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TYNDALL AFB BOMB DAMAGE REPAIR FIELD TEST, DOCUMENTATION AND ANALYSIS

Lawrence D. Hokanson, Capt, USAF
Air Force Weapons Laboratory

October 1975

Final Report

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AIR FORCE WEAPONS LABORATORY
Air Force Systems Command
Kirtland Air Force Base, NM 87117

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The requirement for field testing of the existing Bomb Damage Repair (BDR) procedures under realistic field conditions, the testing of new BDR materials developed for AFWL and requirements for advanced research on debris backfills and equipment package optimization led to the AFWL/Tyndall AFB BDR Field Test. Five major tests and two smaller tests were run. Shortcomings of the AFM 93-2 repair process were identified, including the requirements for more realistic training, improvement in project coordination, improved methods of handling upheaved pavement and a more carefully designed AM-2 ramp attachment system. An optimum Next Page

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equipment package was designed using inventory equipment centered about a large rubber tired dozer. The need for heavier equipment was generally indicated by the field tests. Testing of debris backfill showed that compaction below the six foot level is not important for expedient repairs. Testing of regulated-set cement and PVC structural backfill modules was accomplished with unfavorable results. In general, structural backfill systems cannot compete with debris for expedient repairs. It was determined that development of regulated-set cement is not advanced enough to allow its inclusion in the USAF BDR program at this time. Crater data from 750 lb bombs in clay and sand from 25 lb C-4 charges were collected, and these indicated that the detonation in clay produced the worst repair conditions, although upheaval in the sand subgrade detonations was larger in relation to the crater volume.

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SECTION I

INTRODUCTION

1. IMPORTANCE OF BOMB DAMAGE REPAIR (BDR)

The rapid repair of bomb damaged runways, often called Bomb Damage Repair (BDR), has been a concern of tactical air commanders since the advent of the aircraft and its use in warfare. The extensive use of aerial warfare in World War II brought the subject into sharp focus. Because of the air capabilities of all belligerents and the limited sites for airfields in the South Pacific, the subjects of cratering and BDR began to appear in the literature (ref. 1). Since most recent warfare involving the United States has had US air superiority as a dominant factor, the subject of BDR became, for a time, dormant.

Recent events and situations in which the US finds itself involved demand renewed attention in the BDR area. Because of the improved performance of modern combat aircraft, forward tactical air bases throughout the world are now within easy reach of, and are therefore vulnerable to, attack by enemy aircraft. The hardening of aircraft shelters, and the consequent increased costs an aggressor must pay to destroy US aircraft on the ground, has created a renewed interest in the alternative of directly attacking the airfield pavement system.

The rebirth of interest in penetrating weapons brought about by the Israeli-Arab conflicts, and the decisive military victory scored by Israel in the 1967 war, leaves little doubt as to the consequences of not being able to rapidly recover the use of airfield pavements. From this standpoint, and because the on-target turn-around time for enemy aircraft may be significantly less than the current 4-hour repair criterion, an upgrading of the BDR capability within the USAF is urgently required.

The Air Force Weapons Laboratory (AFWL) was directed in 1971 to turn their efforts toward realizing a one-hour goal in the FY73 Civil Engineering Research and Development program. The requirement was initally foreseen in the TAB VEE study of 1965 which assigned a goal to reduce the time needed for repairs (ref. 2). AF Operations, by AF/XOSNB letter, 25 April 1969, Rapid Runway Repair Capabilities, assigned the goal of "one hour or less"(ref. 3).

2. PAST BDR RESEARCH

The goal of improving the USAF BDR time and repair durability and capability has commanded a large amount of concentrated efforts. The earliest USAF effort in BDR was undertaken in a Rand Study dated 1951.

Test at the USAF Air Proving Ground Center (APGC) conducted in the mid-1960s (refs. 5 and 6) were made to analyze backfill and capping techniques and required equipment. These tests used various backfill systems and several promising capping systems. The results of the test were the elimination from BDR contention of several materials and the design of the present BDR system (ref. 7). The selected system uses AM-2 aluminum matting placed upon a fill of compated select material, which in turn overlays a backfill of compacted crater debris.

In an effort to improve upon this system in time and durability standpoints, the Air Force Aero Propulsion Laboratory (AFAPL) at Wright-Patterson AFB, Ohio, entered into a lengthy research effort involving materials and equipment development (refs. 8 and 9). This research led to the formulation of the Fast Fix cements, and the design and fabrication of a unit capable of pumping this material at a 900 GPM rate. However, it was found that the durability of the Fast Fix cements left much to be desired; the equipment required was large and cumbersome and logistics problems and costs were excessive.

The Aeronautical System Division, Bare Base SPO (ASD/SMB), through requirements for BDR capability within the Bare Base concept performed work in the area of BDR, including the funding of a follow-on to the Fast Fix C-1 work (ref. 10) and a preliminary investigation of the use of regulated-set cement as a BDR material (ref. 11). Subsequently, ASD funded AFWL in the Damage Prediction portion of BDR.

AFWL had first become involved in BDR as a result of the development of the Air Force Armaments Testing Laboratory (AFATL), Eglin AFB, Florida, of a small runway pavement. AFWL investigated the effect this weapon would have on various airfield pavements (ref. 12).

In early 1971, AFWL was directed to expand their Damage Prediction (cratering) program and to begin a concerted investigation of crater repair techniques. Since that time, AFWL has been involved in both field and analytical work in the cratering area (refs. 13, 14, and 15), and has

approached the repair problem in a program involving three major research contracts (refs. 16, 17, 18, and 19). The results of these contracts culminated in the field testing at the Air Force Civil Engineering Center (AFCEC), Tyndall AFB, Florida, which is documented by this report.

Work by other organizations in the field of BDR has been accomplished in the past, including a Navy study in 1964 (ref. 20) and a similar effort by the Army 1962 (ref. 21). Both these efforts dealt with the 4-hour capability. Further Navy interest in repairing small damage is evidenced by their work with the Fast Fix cements. A Rand report covered the subject in conjunction with scaling of damage, in a 1971 report (ref. 22).

3. AFWL BDR TESTS, TYNDALL AFB

a. Objectives.

The objective of this test series was fourfold. First, the existing BDR method, as defined in AFM 93-2, needed to be revalidated. The original work accomplished in this area at the APGC (ref. 6) was in a sand subgrade, utilizing craters created by air delivered weapons. These craters were much smaller than those created by penetrating weapons detonated at optimum depths of burst. Aircraft currently in the inventory were not tested on the repair section at that time. Second, an intermediate goal of improving the AFM 93-2 procedure had been set by AFWL, and information required to improve the procedure was a requirement of this test. Third, there was a requirement to define areas of the BDR process requiring further research; in particular, that involving the use and type of heavy equipment required for the BDR process. Fourth, a requirement existed to test new concepts in the areas of backfill and capping of BDR craters. These included the use of polyvinyl chloride (PVC) pipe modules as backfill material, the use of regulated-set cement foam as a backfill and reg-set cement slurry as a capping, and the use of various soils and/or aggregates as backfill. The testing was required to determine the acceptability of the methods and to guide further work, if required, on

b. Outline of Testing.

The testing at Tyndall AFB was conducted in two phases, the first phase representing the first, second and third objectve and the second phase representing the fourth objective. A total of eight tests, four in each phase, were planned. Only two of the tests in phase two were actually conducted, as a direct result of the outcome of testing at Tyndall AFB and other locations.

(1) Test 1-1.

Test 1-1 was designed to validate under the most realistic conditions possible the AFM 93-2 repair method. In particular, the test was conducted on a pavement section designed to simulate a typical NATO runway pavement. An undisturbed crater created by a 750-pound M117 General Purpose bomb placed at an optimum depth of burst was used. The make up of the BDR team was in accordance with AFM 93-2, both in personnel and equipment; and to ensure that no error existed due to team member selectivity, the 823rd Civil Engineering Squadron, RED HORSE squadron was brought in on temporary duty (TDY) and utilized. The test was carefully documented and timed. Following the repair test, extensive load testing was accomplished on the repaired section.

(2) Test 1-2.

Test 1-2 was designed primarily to determine the stresses and displacements within the backfill system created by the AFM 93-2 repair method. To accomplish this, a newly made crater was backfilled in a manner similar to the operation in Test 1-1, except operations were subjected to suspension at intervals to allow the placement of instrumentation as detailed in appendix II. Following completion of the backfilling and placement of the AM-2 matting, the displacements of the sensors were monitored electronically during loading by a Bison soil gage. The upheaved pavement, or lip area, surrounding the crater was used to test the efficiency and suitability for BDR of various types of equipment within the USAF inventory.

(3) Test 1-3.

Test 1-3 was designed initially to validate any equipment package or technique developed as a result of the analysis of Test 1-1 and 1-2. The Michigan 280, a large rubber-tired bulldozer was found to be the most suitable piece of equipment available at AFCEC for the tasks of crater backfill and removal of damaged pavement. During Tests 1-2 and 1-4, this piece of equipment had appeared to be much more suitable than others tested. It was used as the primary equipment in Test 1-3. Other work in Test 1-3 was to determine the extent to which debris would be available to backfill the crater.

(4) Test 1-4.

Test 1-4 consisted of the repair by various means of four pavement craters created by 25-pound C-4 charges. Repair methods included: (a)

the conventional debris backfill overlaid by select fill and AM-2 matting; (b) debris backfill and select fill overlaid by a 12-inch reg-set cement slurry cap; (c) debris backfill overlaid by a uniform aggregate infiltrated with a reg-set cement slurry (an infiltration cap); and (d) a reg-set cement foam backfill overlaid by a reg-set cement slurry cap.

(5) Test 2-1.

Test 2-1 was conducted in a "reblown" crater, i.e., the same site upon which Test 1-1 was conducted, only cratered by a second 750-pound bomb placed beneath the Test 1-1 repair surface. The main objective of the test was to evaluate the structural PVC module backfill system developed for AFWL by Texas Tech University. The use of regulated-set cement in conjunction with the PVC modules was also of importance.

(6) Test 2-2.

Test 2-2 was originally scheduled to test the use of a uniformly graded aggregate rained into the crater and capped by a regulated-set cement slurry. Due to the extensive difficulties with screeding and control of set time encountered during field testing at the Waterways Experiment Station, during the pouring of test slabs at AFCEC and during Tests 1-4 and 2-1, it was decided to cancel all efforts in this area until further development could be undertaken on regulated-set cement.

(7) Test 2-3.

Test 2-3 was planned as a full-scale (750-pound bomb crater) test of the use of regulated-set cement foam as a matrix for debris in the backfill covered by a slurry cap of regulated-set cement. Test 2-3 was cancelled for the same reasons given in paragrpah 3b(6).

(8) Test 2-4.

Test 2-4 was added as a result of the excellent performance of a regulated-set cement cap formed by infiltrating slurry into a uniformly graded aggregate. This was used on a debris backfill in Test 1-4. Test 2-4 was to consist of the construction of six different configurations of an infiltration cap system and the load testing of these systems. Only three systems were constructed and the test was terminated due to an unexplained degradation of the regulated-set cement during storage.

SECTION II

DESIGN AND CONSTRUCTION OF TEST SECTION

1. DESIGN

Design of the test section at Tyndall AFB was accomplished by the Air Force Civil Engineering Center (AFCEC) under the direction of AFWL. The basic requirement was simply that the pavement system utilized in the test should approximate as closely as possible tnose systems presently existing on USAF air bases located in NATO nations. This would allow testing under conditions similar to actual field conditions. Information formerly gained by field surveys conducted worldwide by AFCEC was studied, resulting in the recommended test section shown in figures 1 and 2.

Size of the test site layout was based on the requirement for enough area to explosively excavate three craters, none of which would be damaged by any other. The overall configuration and the test site location are shown in figures 3 and 4, respectively.

2. CONSTRUCTION

Material used in the construction are detailed in tables 1 and 2. Because of a shortage of, and the long lead time for delivery of, the original Eufala Clay used for backfill, the last 2 feet of the clay backfill consisted of a local clay known as Florida Clay. Figures 5 and 6 were taken during construction. Figure 5 illustrates the placement of the clay material, and figure 6 illustrates the placement of the final 2-inch lift of asphaltic pavement.

To satisfy test requirements listed in section I, the clay backfill was selected to be 10 feet in depth. This allowed the weapon to be placed at a depth of burst close to optimum, insuring the worst damage possible with the M-117 weapon.

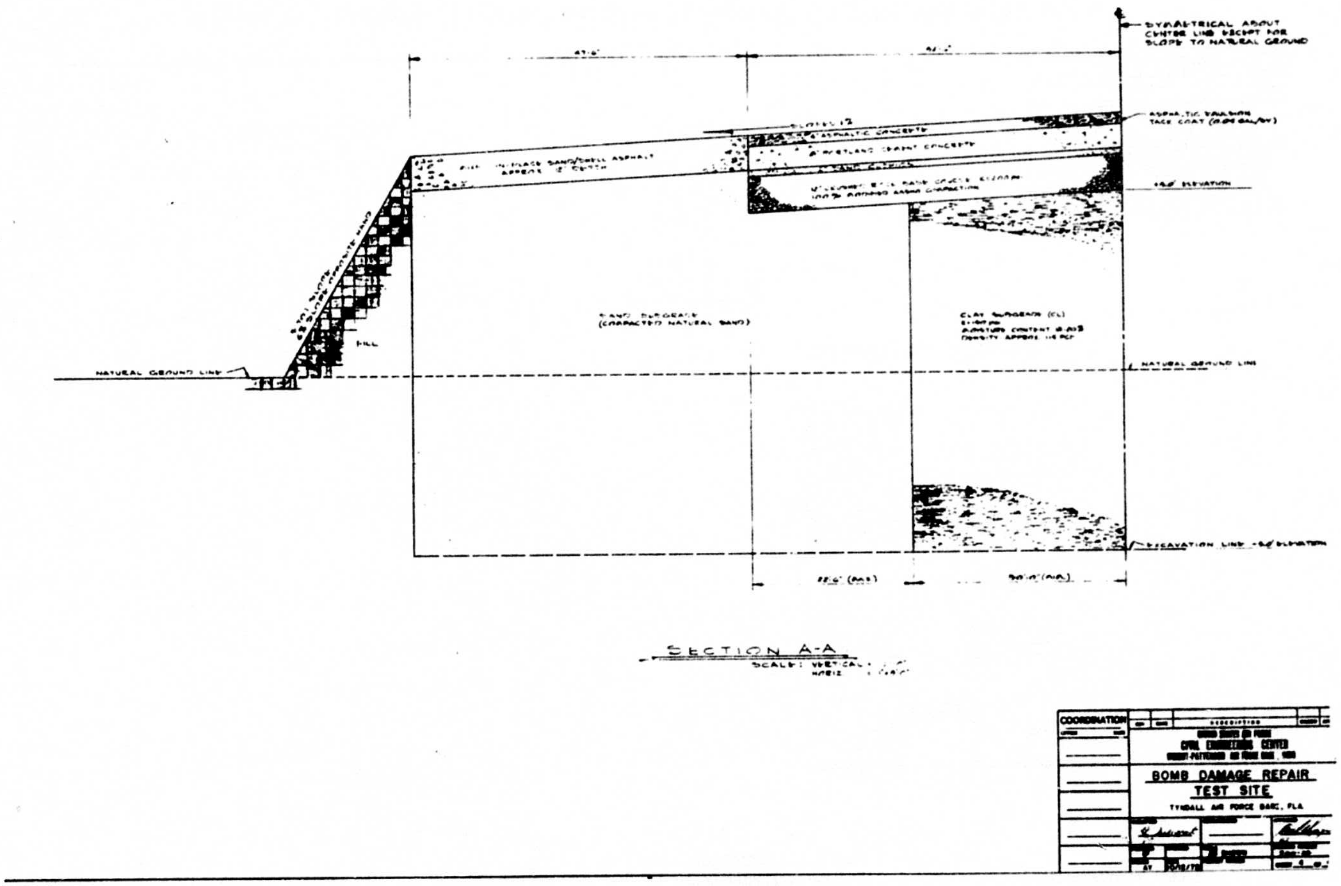


Figure 1. Tyndall AFB BDR Test Site Cross Section

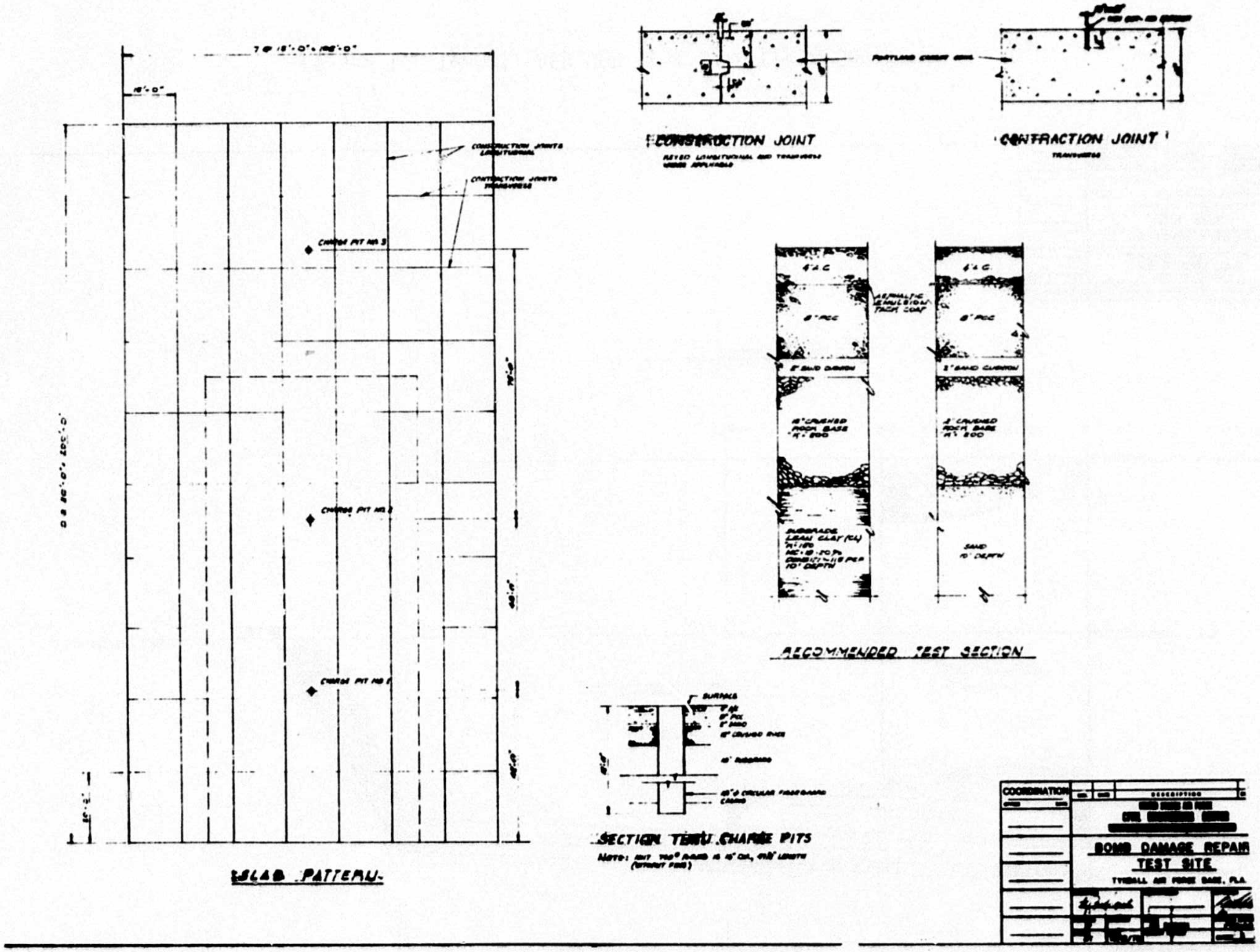


Figure 2. Tyndall AFB BDR Test Site Structural Section and Joint Layout

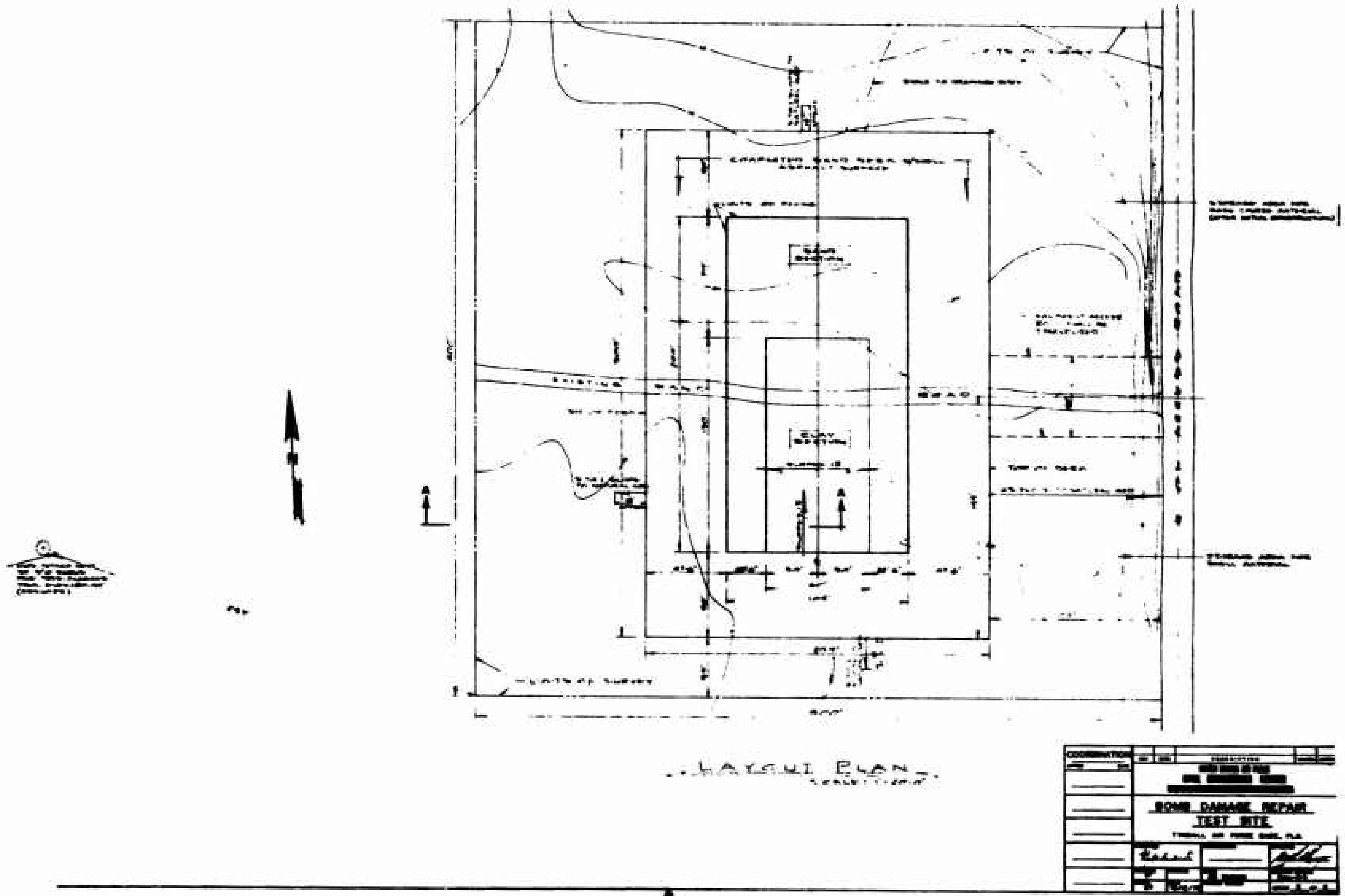


Figure 3. Tyndall AFB BDR Test Site Plan View

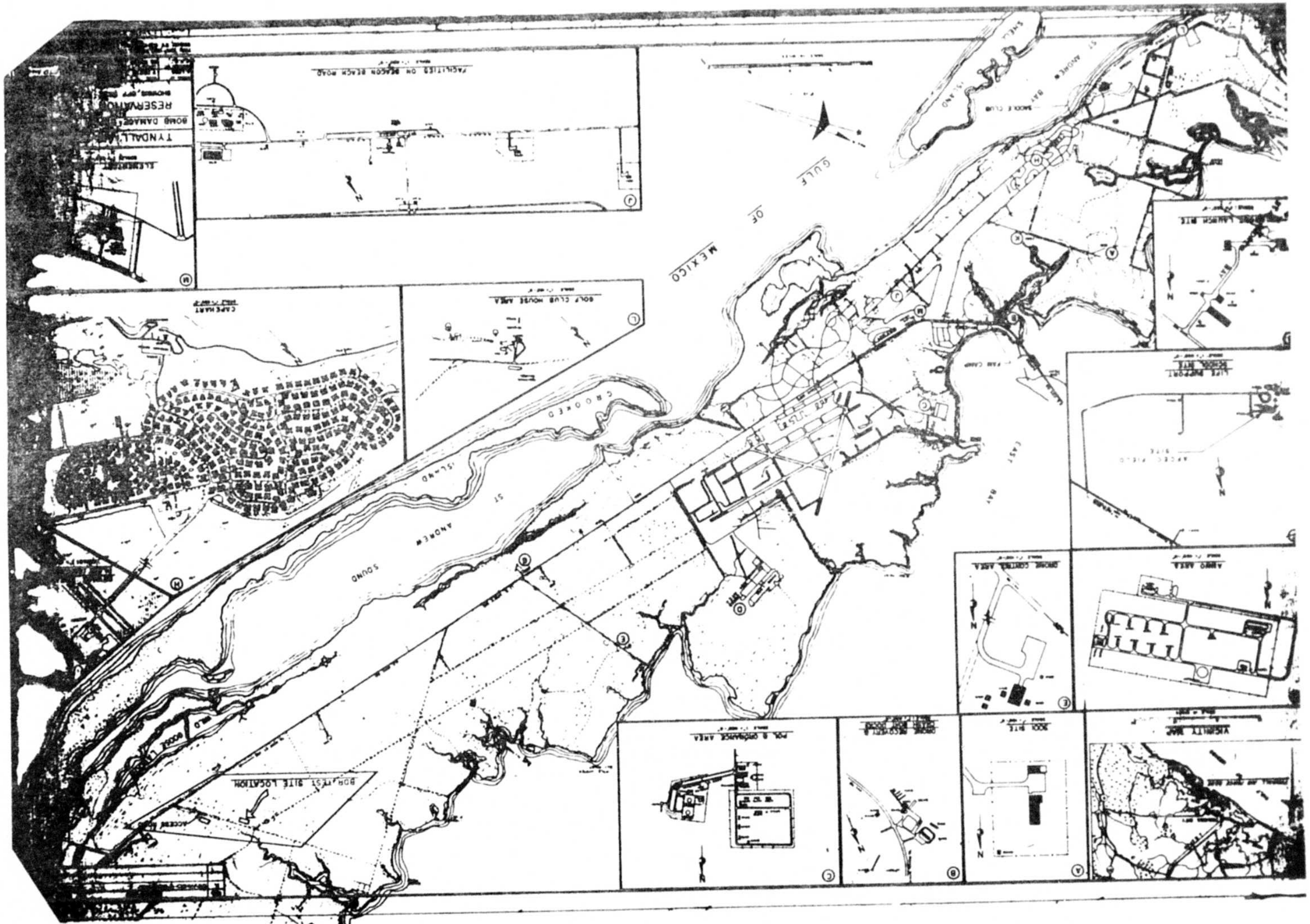


Figure 4. Tyndall AFB BDR Test Site Geographical Location

Table 1

BDR TEST SITE CONSTRUCTION MATERIALS

	SAND FILL	EUFAULA CLAY	FLORIDA CLAY	BASE COURSE
Unified Classification	SP	-	SC	GW
Average	-	SC	-	-
Range	-	MH-SC	-	-
Percent Passing #200	-	-	23	-
Average	-	47	-	-
Range	-	30.2-72.5	-	-
Liquid Limit	-	-	69*	-
Average	-	41	-	-
Range	-	31-52	-	-
Plasticity Index	-	-	38*	-
Average	-	18	-	-
Range	-	9-28	-	-
Specific Gravity	2.68	-	-	-
CE55 Optimum Density	97.7	-	117.4	136.3**
Average	-	120.7	-	-
Range	-	118.2-121.4	-	-
Optimum Moisture Content	19.1	-	10.3	12.1
Average	-	12.5	-	-
Range	-	11-14.4	-	-
In Place Density	-	-	-	-
Average	86.7***	110.0	87.2-109.7	143.1-150
Range	79.6-92.7***	84-124.6	100	146.3
In Place Moisture	-	-	-	-
Average	6	16.4	13.5	2.9
Range	4.2-8.6	11-19.9	11.4-16.5	2.4-3.4
Average Percent Compaction	89	92	85	107
Approximate Thickness	-	8	2	-

* Determined on -200 material; -40 material slid in the bottom of the liquid limit device due to dilatancy. Florida Highway Department testing on -40 material indicated a LL of 38 and a PI of 19.

** Based on a comparison of field compaction obtained, the dynamic method of ascertaining maximum dry density under estimates optimum density obtainable.

*** Determined on last 1 foot of fill.

Table 2

BDR TEST SITE CONCRETE STRENGTH, 28 DAYS

	RANGE	AVERAGE
Flexural Strength	437-654	517
Compressive Strength	3430-4509	3929

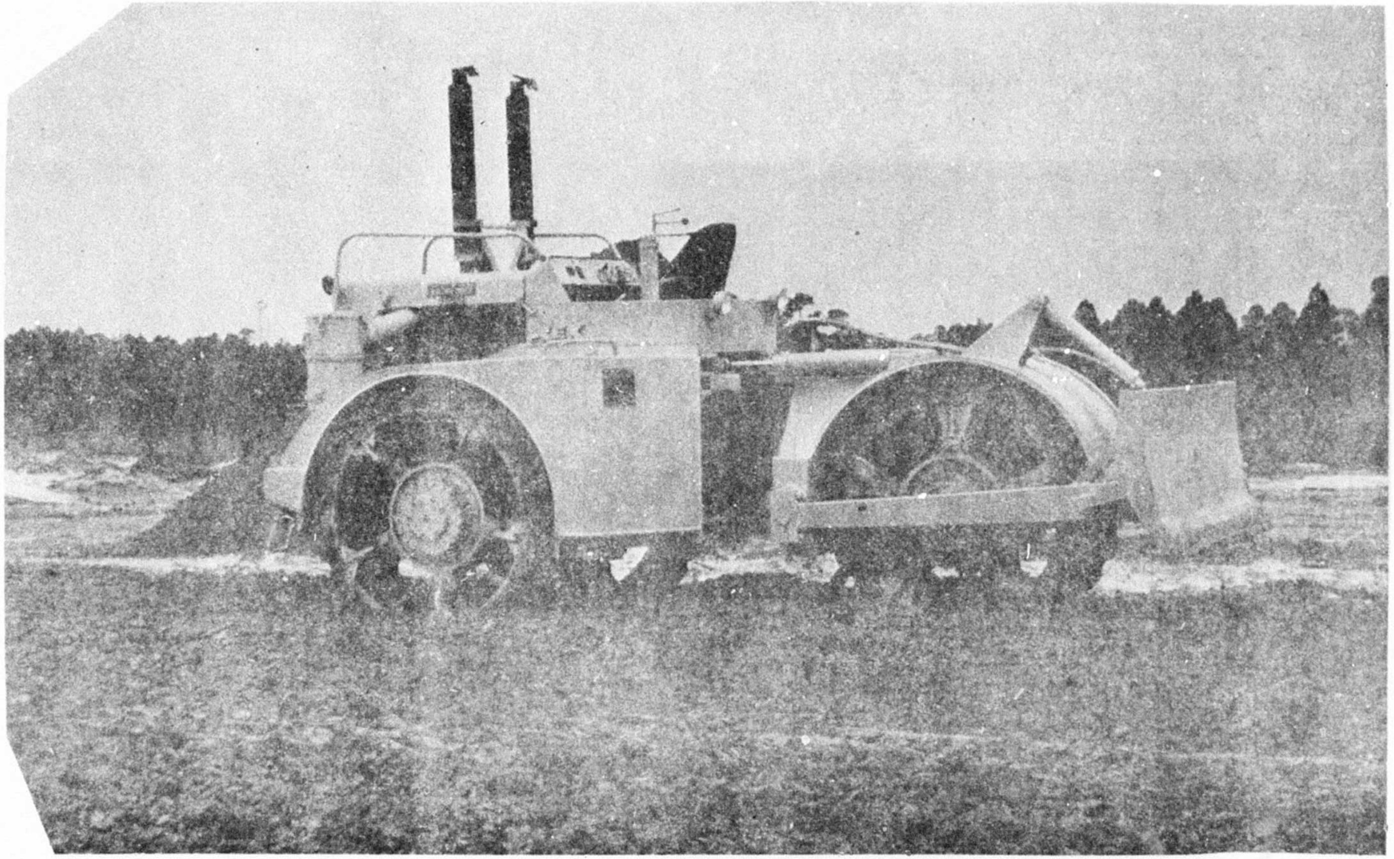


Figure 5. Clay Subgrade Material and Compaction Equipment during Construction

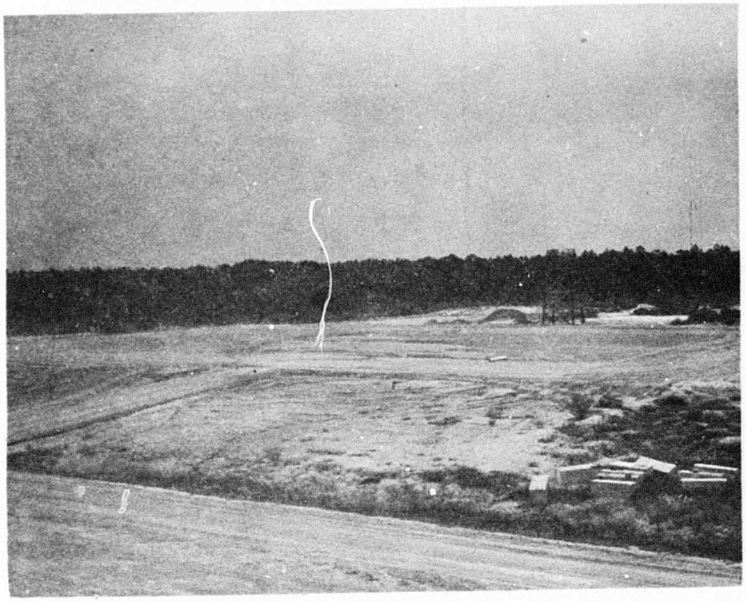


Figure 6. Completed BDR Test Site: Note viewing tower near center rear of test pad

SECTION III

TEST 1-1

1. OBJECTIVES

a. Primary Objectives.

The primary objective of Test 1-1 was the validation of the current USAF BDR technique as presented in AFM 93-2. Other objectives were considered when consistent with the primary objective. These include time and motion studies on equipment used, analysis of the performance of a debris backfill, analysis of the performance of the AM-2 matting used as a cap and the gathering of important cratering data.

b. Objectives Related Directly to AFM 93-2.

Objectives related directly to AFM 93-2 included the careful timing of the overall repair process and the various subtasks included in the repair process. The suitability of the repair technique to the conditions which would exist following an air strike was carefully considered, as were areas where the repair technique could be improved either through minor or major revisions.

c. Time and Motion Studies.

Time and motion studies were performed upon the technique with the objective of determining problems associated with the BDR process and the capability of the equipment and personnel to surmount these problems. These studies also provide data on which to base estimates of the time revised repair techniques would require and on which design of new BDR equipment could by based.

d. Backfill Study.

Information was gathered about the backfill performance to allow determination of the depth to which the crater could be filled with selected debris and determination of the deflections within the backfill under laoding.

e. AM-2 Study.

Information was gathered on the AM-2 matting to determine if this type of capping system was adequate for the optimum BDR capability being sought. It provided deflection data showing the performance of AM-2 under

the heavy wheel loadings exerted by F-4 and F-111 aircraft and valuable information on the roughness generated by unequal deflections as the aircraft gear crossed various portions of the repair.

2. TEST PROCEDURE

The test was conducted under the most realistic conditions yet attempted for a BDR evaluation. First, the special pavement section was designed and built to be a synthesis of common systems encountered at USAFE bases. Second, all equipment, and only that equipment, called for in AFM 93-2 was utilized as shown in table 3. Third, USAF personnel of the exact grade and skill level required by AFM 93-2 were utilized, as shown in table 4. The only guidance given to this BDR team was that contained in AFM 93-2. Fourth, the crater to be repaired was made by detonation of an actual 750-pound bomb implanted at what was calcualted from the results of previous testing to be the optimum depth of burst.

Table 3

VEHICULAR EQUIPMENT, AFM 93-2 AND TEST 1-1

BDR Vehicle Equipment-TA 010

Nomenclature	Quantity AFM 93-2	Quantity Test 1-1
Truck, Pickup ½ Ton, GED, 4x2	2	1
Truck Tractor, 10 Ton, GED, 6x4	3	1
Truck Dump, 5 Ton, 4x4	15	5
Semi Trailer, 20 Ton	3	1
Tractor, Full Track, SZ 4	3	1
Grader Motorized, 6x4	3	1
Tractor, Industrial, Wheeled, SZ 5	2	1
Loader, Scoop, Tired, 2.5 CY	7	3
Crane, Truck Mtd, 20 Ton	1	1
Sweeper, Rotary, Towed	2	1
Sweeper, Vacuum, Self-propelled	2	1 (simulated)

The approved repair method requires the simultaneous repair of three craters, each made by a 750-pound weapon. To economically test the method, a reduction in scale to one crater was made. The BDR package was necessarily tailored to one crater. Tables 3 and 4 show the requirements for the three crater capability and the reduced requirements for one crater in terms of both men and equipment. The most serious drawback of this scale-down was the exclusive attention given to one crater by the OIC and NCOIC, and the part-time availability of a third loader at the crater site.

Table 4

PERSONNEL REQUIREMENTS, AFM 93-2 AND TEST 1-1

RANK	AFSC	AFM 93-2 CRITERIA TOTAL REQUIREMENT	AFM 93-2 CRITERIA CRATER REQUIREMENT	ACTUAL TEST 1-1* REQUIREMENT
Lt	5525	1	0	1
CMS/SMS	55191	1	0	1
MSG/TSG	551XX	7	2	3
SSG/SGT	551XX	10	2	4
SGT/A1C	551XX	7	0	1
Any	551XX	1	0	1
SSG/SGT	551X1	6	2	2
Any	55XXX	15	0	5
Any	5XXXX	4	1	1
SSGT	553X0	1	0	0
SGT	553X0	1	0	0
SSGT	552X4	1	0	0
Any	Any	66	22	22
Total		121	29	41

* Includes essential at-large repair team members table 4 - Personnel Requirements, BDR Field Test

The presence of OIC and NCOIC at the crater site meant that essentially every piece of equipment was directed from the ground. As will be explained later, this is an ideal situation, and can be counted on to increase the efficiency of the equipment involved.

A further deviation from reality which must be considered in raw time assessment of this exercise was the assemblage of all personnel and equipment prior to the assumed detonation time (i.e., time at which the team was instructed to begin reapir), and the prior knowledge of which crater to repair. The determination of craters to repair could conceivably be extremely time consuming, and could in itself take up to 30 minutes (ref. 23).

To document this test, several media were utilized. A time-lapse film of the entire operation was made at varying reduced frame speeds. Both still and movie photographic documentation was made. Video taping as an engineering data tool was used, although not with success. In addition, skilled field personnel were assigned as observors and kept notes on tape which were later transcribed. The video equipment failed to function properly, possibly as a result of the rather harsh environment at the test site. The video tape that was produced suffered from a lack of resolution required to study the

pavement actually being moved by the equipment. Dependable equipment with better resolution should be tried in the future for this type of testing.

A collection of data regarding the cratering event which could be used for other AFWL BDR projects and which would add to the general data base of cratering information was made and the quality of the repair was tested to determine the feasibility of the repair method from the standpoint of required engineering properties of runways.

3. TEST RESULTS

The repair procedure comprises seven basic operations, six of which were tested. The final operation, runway marking, was not tested, as being irrelevant to these tests. Simulation of this event was not attempted because it would have provided little or no information on the actual task and its relationship to the remainder of the BDR process.

The duration and sequence of each operation is shown in figure 7. Appendix I constitutes a time sequence listing of Test 1-1. The operations are listed below.

Survey and determination of craters and areas to be repaired, including a rough layout of 50-foot by 5,000-foot runway.

Cleanup of debris and backfilling of crater with debris.

Clearing of the lip area and all heaved pavement.

Placement, compaction and final grading of select fill material.

Mat fabrication.

Mat placement.

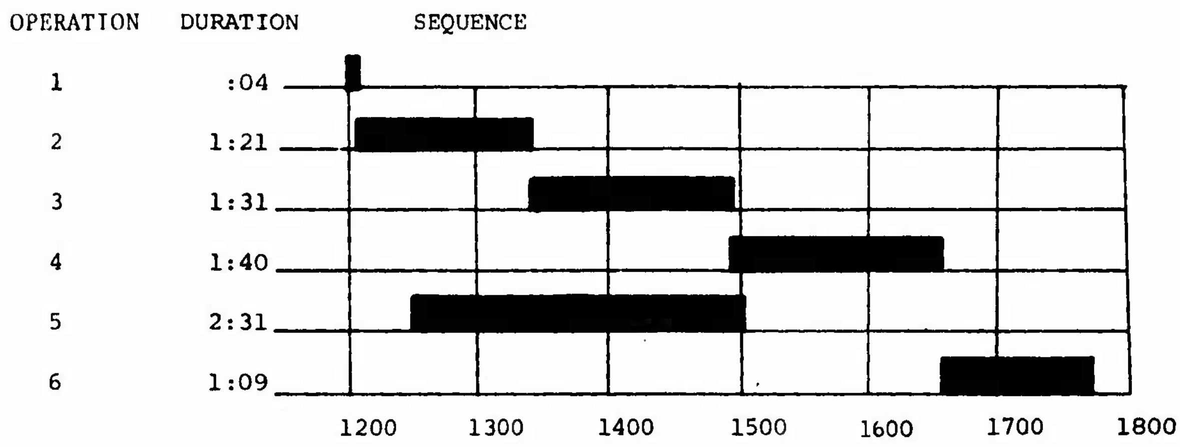
Runway marking.

From figure 7, observations by trained observers and the time lapse films, many problem areas were identified. These problems are presented below integrated into six operations actually tested at Tyndall AFB during Test 1-1.

a. Survey and Determination of Damage and Areas to be Repaired.

Although it was immediately obvious which crater to repair, the BDR team wasted much valuable time repairing areas which would have fallen outside the standard width for expedient repair; 54 feet to accomodate the AM-2

mat. Time was also lost in this respect by special care being given to not damaging with equipment pavement which lay outside a 50-foot width. In addition, large pieces of concrete removed from around the crater were carried to an excessive distance. A change in the current manual directing the NCOIC or OIC to mark out the areas described above should be made.



1. Damage, assessment and runway layout
2. Cleanup and backfilling
3. Lip and heaved pavement clearing
4. Base course placement, compaction, grading
5. Matt fabrication
6. Matt placement

Figure 7. Test 1-1, Operation Sequence and Duration

b. Cleanup of Debris and Backfilling of Crater with Debris.

(1) Ejecta Spread and Quantity of Debris Available for Backfill

Because of the spread of the ejecta, the ejecta judged as suitable for backfilling by the BDR team was less than the crater volume. Figure 8 shows the ejecta spread in Test 1-2, which was similar to Test 1-1. Extra material was obtained from the shoulder area of the runway and by utilizing coarse aggregate that had been stockpiled for another test. It became evident that the amount of ejecta may not be sufficient to fill the crater

if large pavement chunks are discarded. A possible solution is the careful analysis of material on the runway shoulder and inclusion in the base contingency plan of the location of shoulder material suitable for backfilling. Shoulder areas also can be used as stockpile areas for acceptable backfill materials of low value at bases where the ejecta itself may not be suitable. As an example, sand shoulders could serve as stockpiles for locations where a high water table with a highly plastic saturated clay material would preclude using the ejecta as backfill.

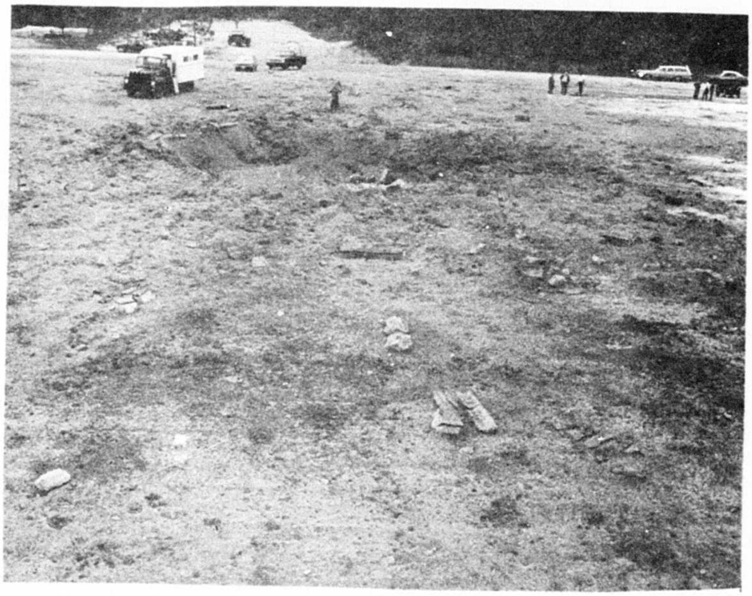


Figure 8. Crater Created by M117 Weapon for Test 1-2, Crater is Similar to Crater Utilized for Test 1-1

(2) Determination of the Suitability of Crater Ejecta for Use as Backfill

In Test 1-1 a large amount of time was expended in removing broken concrete slabs from the crater area (figure 9) even though a shortage of backfill material existed. This material would have made excellent backfill; however, AFM 93-2 provides no guidance for determining suitability. The solution to this lies both in training of potential BDR OICs and NCOICs and in providing more guidance in AFM 93.2.

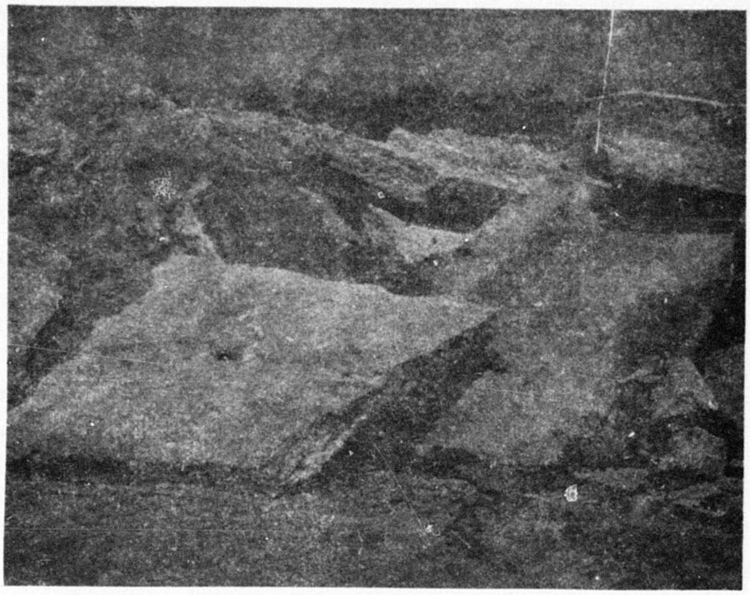


Figure 9. Test 1-1, Broken Slabs Removed from AM-2 Air Field Patch Assembly Area

(3) Compaction of Backfill

In this test a stiffness, K_u, value of 225 PCI was obtained, indicating excellent compaction. However, the equipment available for compaction was minimal, and other types of material would not have been as easily compacted by the TD-20 tractor and No. 645 loaders which performed the bulk of the compactive effort. The compaction problem does not have a single solution; each base must be provided with information on the type of compaction equipment and methods most suitable for their subsurface conditions. For example, a saturated clay would not respond to compaction by most equipment if a high water table existed, and a sand would require water to obtain suitable compaction. Compaction equipment more suitable for working on the backfill area of the crater is required.

(4) Suitability of Selected Equipment Used in Backfilling of the Crater

(a) Compactor

The hand-operated compactor in the current package is of no

value for craters of this magnitude. Compaction equipment towed by either the tracked dozer or the large loaders is required. At least two types of compactors should be included in the package, or one compactor should be matched to the subgrade or backfill soil to be used at a particular base. For this exercise, a sheepsfoot compactor would have been ideal. In the sand subgrade in a later test, a sheepsfoot would have been of little value, although a vibrating drum roller would have been of value. Likewise, the compaction afforded by the tracked dozer was excellent in the clay subgrade but would prove to be of less value in the sand subgrade.

(b) Grader, Motorized

This item was instrumental in clearing the runway of debris, particularly for the AM-2 patch assembly area (figure 10), but served no purpose in backfilling of the crater.

Figure 10. Test 1-1, Motorized Grader Cleaning Small Debris from AM-2 Air Field

(c) Loader, Scoop, Tired 2.5 C.Y.

The three loaders used were, with the dozer, the most valuable items in the backfilling. However, for the backfilling function the time of repair would have been considerably improved by the use of larger machines.

This was demonstrated by the amount of work accomplished by the tracker dozer with its capability for shoving or pushing larger quantities of debris and ejecta, into the crater in each pass, and by later tests with a larger rubber-tired bulldozer. In this initial function, the loaders were used exclusively in the dozer capacity (figure 11) and as such were less effective than desired. As seen in figure 12, the loaders had to carry debris to the crater rather than being able to push directly into the crater. The use of the third loader at the crater site was not in conformance with AFM 93-2. Only two are set aside for each crater, with one being limited to the stockpile, for a total of seven loaders in the three-crater repair package. These loaders were equipped with special buckets called "4-1" buckets, allowing the machine to serve as a loader, dozer, fork lift or clam.

(d) Crane, Truck Mounted

This item proved to be of no value and was removed from the site. While great versatility exists with this piece of equipment, stringent BDR time requirements rul out its use in most BDR applications.

(e) Tractor, Full Track SZ-4

This item proved to be the most versatile and useful piece of equipment in the test. Its capability to push large amounts of debris into the crater and to "walk" into the crater to compact material was excellent (figure 13). However, the large tread size made the actual compactive effort smaller than desirable. The cleats on each track contributed to compaction, due to the near optimum moisture content of the clay material. A portion of the job done by this item could be done with either larger loaders or large rubber-tired dozers; however, the particular type of dozer required depends on the subgrade condition at the base where the BDR capability is required. Figure 14 demonstrates the extra capability of a large dozer versus front loaders. The left side of the crater was worked on by two to three loaders, while only the TD-20 dozer had worked on the right side.

(5) Control of Additional Damage to the Pavement.

In this pase of the repair, damage by improper equipment or unskilled operators must be carefully controlled. It is highly desirable to carefully lay out the 50-foot by 5,000-foot emergency runway before equipment is introduced. This would avoid "walking" of tracked vehicles on the pavement to be used and limit the area where a cushion of soil must be applied to protect the pavement. In this test several large gouges (figure 15) were made by the use of loaders operating alternately in the dozer and loader configureation with the 4-in-1 bucket.

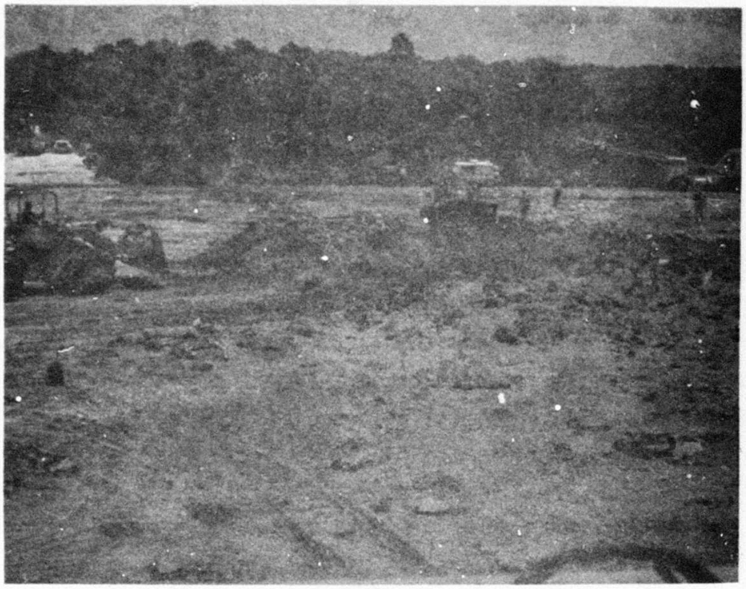


Figure 11. Test 1-1, AC 645 Loader Attempting to Push Debris Directly into Crater

Figure 12. Test 1-1, AC 645 Loader Forced to Lift and Drop Debris into Crater

Figure 13. Test 1-1, TD 20 Full Tracked Dozer Pushing Large Debris Directly into Crater

Figure 14. Test 1-1, Comparative Work Done by TD 20, Right Side, and Three AC 645's, Left Side, in Equal Period. Note Minimum work accomplished by 645's since repair progress shown in figure 11.

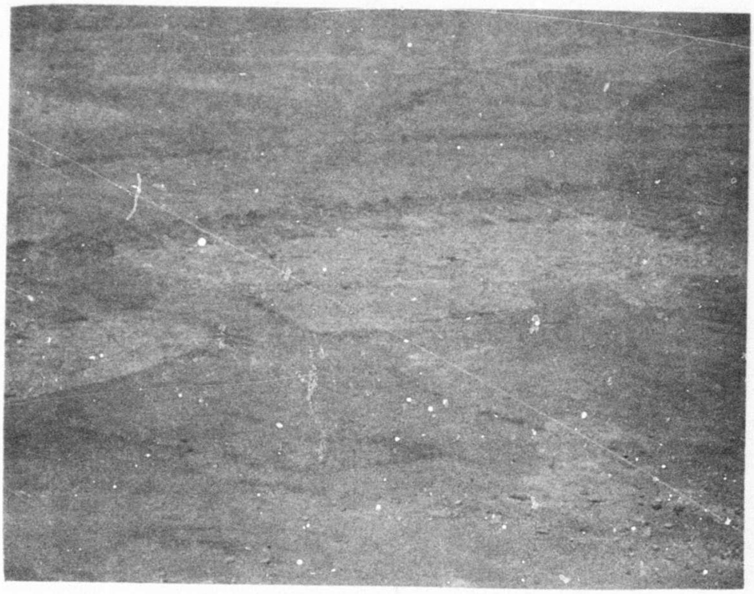


Figure 15. Test 1-1, Pavement Gouges Made by AC 645 Loaders with Four in One Buckets

(6) Equipment Control at the Crater.

Because of the confined area in which the repair equipment is working and due to the number of pieces of equipment (four to eight at any given time), more accurate control of the equipment at the crater is required. This is particularly true in view of the time limit and the danger of poorly utilized equipment being counter-productive by either unnecessarily adding to congestion or extending pavement damage. It was suggested by nearly all members of the BDR team that one operator be provided as a ground man for each piece of equipment at the site. The duties of this ground man would be to direct the equipment in the most productive manner in coordination with other equipment at the crater site. Each ground man would be either capable of operating the equipment he is directing or be well versed on the capabilities of the equipment. This item relates closely with operator fatigue, an item covered below. In general, the concept of fatigue applies to all equipment working at the immediate crater site, and applies to operations 3 and 4 as well as operation 2.

c. Clearing of the Lip Area and Final Preparation of the Subgrade

(1) Concrete Lip Removal.

This was the most time consuming and complex problem faced in this exercise. The broken and badly upheaved concrete was readily and easily pushed into the crater early in the repair by the dozer. However, once the obviously damaged material was pushed in, the equipment operators did not recognize the further upheaved areas that required removal. This problem was aggravated by the inability of the OIC to check for upheaval until the pavement had been thoroughly cleared of ejecta, and this came late in the backfill process (1351, figure 16).

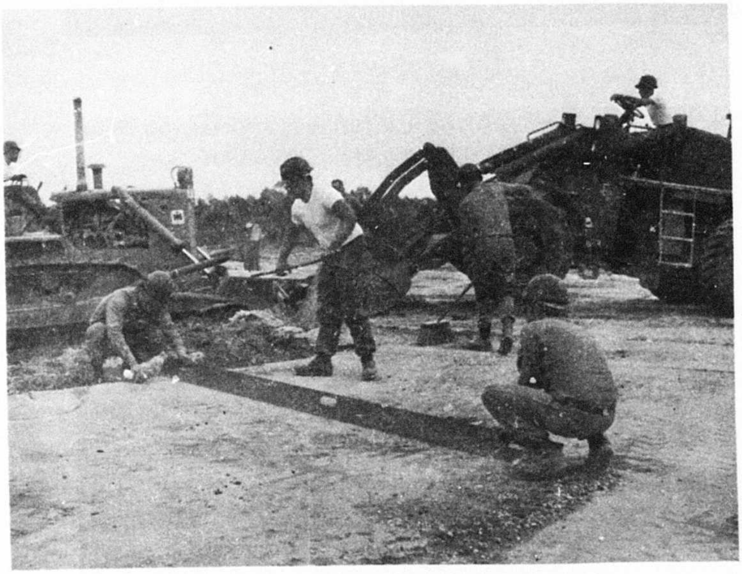


Figure 16. Test 1-1, Identifying Subtly Upheaved Pavement with Specified Straight Edge

Once the pavement to be removed was identified, a time-consuming process of lifting the pavement out with a dozer or loader blade (figure 17) and then loading the debris into a loader bucket began (figure 18). The equipment in the package is not suitable for this use. Since the overlay of asphaltic concrete physically hides the joints in the pavement, it is extremely difficult to find a point at which the concrete can be broken for removal.

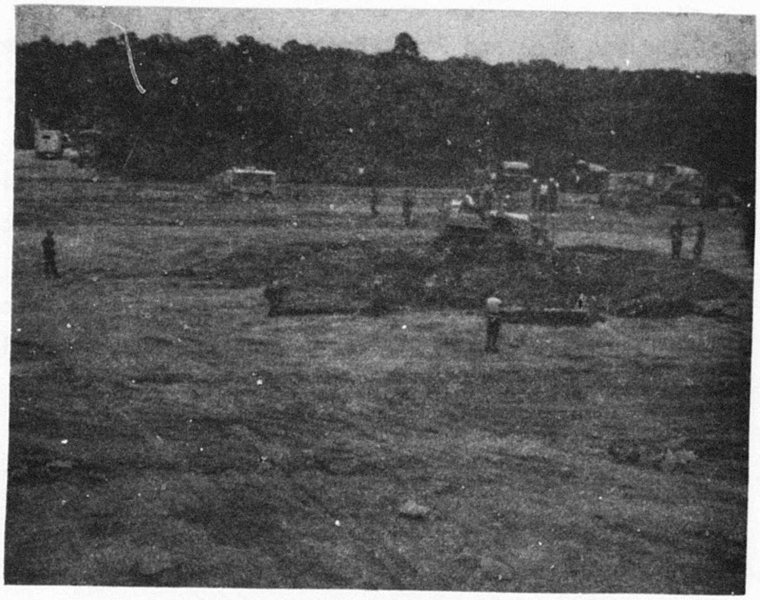


Figure 17. Test 1-1, TD 20 Lifting and Breaking Free Large Upheaved Pavement Sections

Figure 18. Test 1-1, TD 20 Inside Crater Aiding AC 645 in Removing Large Upheaved Pavement Sections

It is easy to damage or uplift pavement previously undamaged when removing large pieces of damaged or upheaved pavement, thus increasing the scope of work. Because most tests with BDR have been on simulated craters, this problem has not been previously dealt with and was unexpected by the BDR team. Several pieces of equipment were tested in Test 1-2 to determine their suitability for this work. The concept of removing these large concrete pieces from beyond the crater perimeter rather than from inside the crater is especially important, since activity in the crater (compaction) or the condition of the soil inside the crater may not allow working from the inside. The identification of these upheaved areas is a serious problem. However, only a 50-foot wide runway is required, and in many cases the entire perimeter of the crater will not require cleaning. Also, it may be possible to utilize larger equipment to literally slide the upheaved pavement areas over the base course and into the crater. This concept was tried with a large (400-HP) rubber-tired dozer in Test 1-2.

(2) Equipment Suitability of Selected Items.

(a) Tractor, Full Track, SZ-4.

This piece was used to lift the upheaved pavement up and break it free so that it could be picked up by loaders and hauled from the area (figure 18). The lack of nimbleness and precise control of the dozer blade hindered its usefulness for this task, and in some cases extended damage by uplifting previously undamaged pavement.

(b) Loader, Scoop, Tired 2.5 C.Y.

The four-in-one buckets on these pieces of equipment were not designed for lifting pavement in this manner (figure 19). All work with these had to be within the crater unless aided by a second piece of equipment in the crater. This operation may not be possible with all craters. The small size of these loaders limited their ability to lift larger pieces of pavement.

(3) Implications of Reinforcing.

The removal of upheaved pavement would be extremely difficult to overcome if even a minimum amount of reinforcing were in the pavement. The presence of reinforcement would require either removing larger pieces of pavement or the cutting of reinforcing steel. Testing on the effects of reinforcement is currently being conducted by AFWL (ref. 24).

Figure 19. Test 1-1, AC 645 Attempting to Remove Broken and Upheaved Pavement Sections with 4-in-1 Bucket

d. Placement, Compaction and Final Grading of Select Fill or Base Course Material

(1) Material Delivery Time.

A total time of 1 hour and 17 minutes elapsed from the dumping of the first material until the last load was delivered. Less time than this is required for the compaction and placement, which means the repair itself could be shortened if this delivery time could be improved. Three ways exist of improving the time. More trucks and loaders could be used, trucks and loaders with a larger capacity could be used, and/or the material could be stored in closer proximity to the site. The best solution is the temporary stockpiling of the material at the crater site. In this exercise, room was available to do this, and the hauling could have been nearly completed by the time the material was required. It could have been easily drifted into the repair by the loaders and the tracked dozer. All five trucks were standing-by loaded for 1 hour and 10 minutes prior to the requirement for base course but were unloaded only when the material was actually needed. Inclusion of directions for temporary stockpiling in AFM 93-2 could save up to 45 minutes of the repair time.

(2) Base Course Compaction.

As indicated by the load-bearing capability of the final repaired area, proper compaction of the base course (select fill) was not accomplished. The current BDR package does not contain the proper equipment to compact select fill material. A vibrating drum or sheepsfoot roller would be especially helpful. The compaction accomplished by wheel rolling with the loaders and grader was not acceptable. Also, the moisture content of the material was inadequate, indicating that either the stockpile moisture must be controlled and monitored or water must be available at the repair site to ensure optimum moisture content of the material.

(3) Final Grading of the Select Fill.

This is a crucial part of the repair when high-performance, heavy wheel-load aircraft are to operate from the repair. In this exercise variations in the surface caused extreme deflections of the mat under loading with an F-4C load cart at 29,000 pounds. Proper equipment and instructions for final grading are not provided in AFM 93-2. This problem is compounded by the two way slope of a runway, usually having either a gradient or vertical curve in the longitudinal direction and a drainage or crown slope in the transverse direction. A rapid survey system may have to be devised to solve this problem.

e. Mat Fabrication.

This operation was fairly straight-forward. However, a mis-start by the BDR team demonstrated the requirement for careful training and more precise instructions on the fabrication of the mat. Since mat fabrication took 2 hours and 31 minutes, this item is not currently on the critical path of the repair. Typical mat construction is shown in figure 20.

f. Mat Placement.

(1) Assembled Mat Relocation.

Actual placement of the mat went quite smoothly. The two AC 645 front loaders provided adequate towing power. The move was made by first pulling the mat to a position alongside the repair area (figure 21) and then pulling the mat laterally across the repair (figure 22). Some displacement of the prepared base course did occur and could have caused local depressions in the finished mat surface.

Figure 20. Test 1-1, AM-2 Airfield Patch Being Assembled

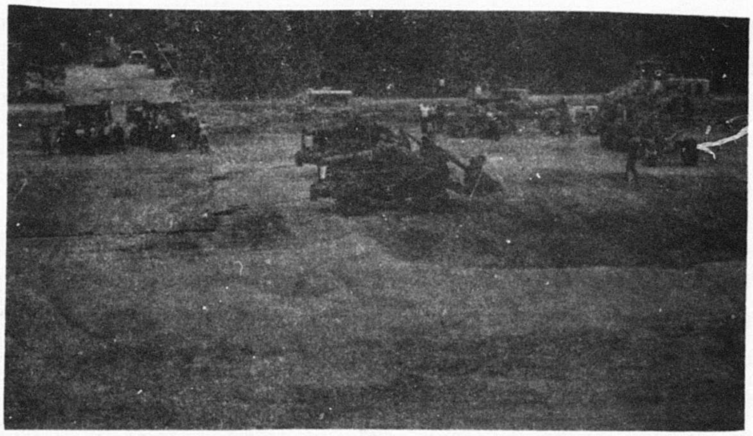


Figure 21. Test 1-1, AM-2 Airfield Patch Assembled and Being Towed into Position Longitudinally

Figure 22. Test 1-1, AM-2 Airfield Patch Being Towed into Position Laterally

(2) Mat Size.

The size of the standard BDR kit must be made more flexible to allow use on craters of various sizes. Instructions contained in AFM 93-2 for assembling the mat are for one size only. The use of mat for small repair areas, or multiple repair areas is unproven. It is now known if the dynamic characteristics of an aircraft could tolerate four or five small patches in a limited area. The requirement for all mats to span the entire width of the expedient runway is also wastful; however, it is a requirement to minimize differential roughness between the main gears.

(3) Ramps.

Problems were encountered in the placement of the ramps due to the crown on the pavement section. The ramp was not designed to be able to follow breaks in slope or vertical curves. Figure 23 shows a 1/4-inch height differential between adjoining ramp sections. A redesign of this may be a requirement, although the latest ramp design was not tested.

(4) Anchoring.

The current anchoring system is not suitable for asphaltic concrete overlayed runways. The expansion sleeves readily pull out of asphalt. In

addition, the drills used on the sleeve holes are standard rotary electric drills, and do not produce holes in concrete at a high enough speed to be satisfactory. In this exercise, the anchoring system was not completed, nor could it have been completed in a reasonable time. Further problems exist with the anchoring system, not the least of which is no criteria upon which to judge the performance of a system. Uplift and shear must both be considered in designing an anchor, and neither design value is known. This must be determined before an effective design can be made. An interim alternate system was devised by AFCEC in Test 1-2 and is covered later in this report.

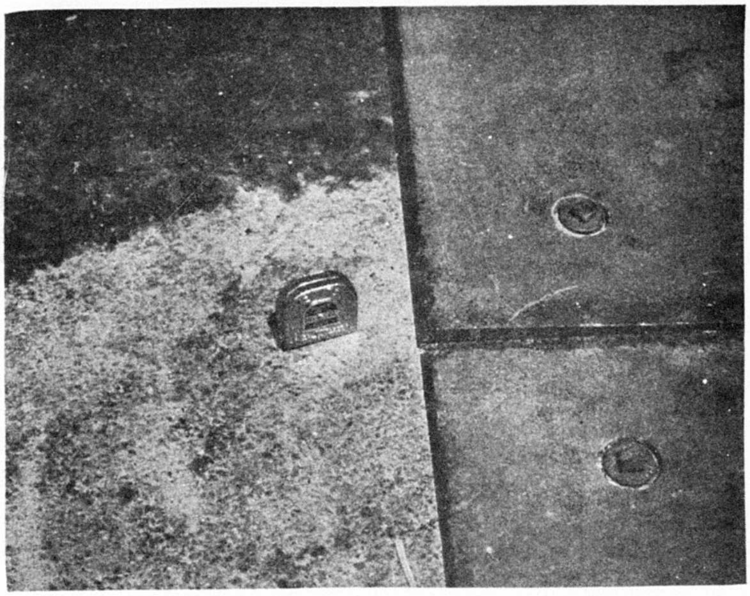


Figure 23. Test 1-1, Mismatch of AM-2 Airfield Patch Ramp Sections Due to Crown in Runway

g. General Areas

(1) Operator Fatigue.

Because of the requirement of rapid repair, equipment operators must operate at their peak capability and with maximum mental alertness throughout the repair process. This, combined with the rough ride characteristics of and physical exertion required to operate equipment such as the TD-20 and AC-645 rapidly fatigues operators. This was noticeable on Test 1-1. The

speed and accuracy of equipment operation after an hour was dramatically reduced. It is suggested that a second operator be provided for key equipment to work on the ground guiding the equipment for its maximum effectiveness, and allowing the primary operator to be spelled once an hour. A realization of the human factors involved must be paramount in design of the repair process. If the operator can only operate at 80 percent efficiency after an hour of continual work, the equipment will be 80 percent or less efficient, proportionately increasing the repair time.

(2) Operator Training.

Past crater repair training has utilized simulated or exacavated craters. The explosively detonated craters at Tyndall AFB presented many aspects of pavement damage that the operators and supervisors had not envisioned prior to testing. The resulting excessive repair time required is not necessary. Training should be devised which ensures that all BDR team members know not only what they must do but why. Time-lapse photographic coverage was taken of Test 1-1, and Test 1-2 yielded information on the crater lip. It is suggested that viewing these photographs could be an excellent starting place for the training of BDR team members.

h. Time Results, Test 1-1

(1) The test was terminated at 1745, 5 hours and 45 minutes after the repair team was dispatched to the site. Because of the difficulties encountered in anchoring the matting to the runway section, the anchoring was not completed. Runway marking was not accomplished. All other phases of the repair were complete.

(2) A careful consideration of the most time-consuming events of the repair show that if the repair procedures were modified the repair time would be approximately 4 hours. Revisions of AFM 93-2 plus intensive BDR training are essential to ensure that a 4 hour capability exists. Testing at Aviano, Italy subsequent to these tests at Tyndall AFB has demonstrated a 4 hour capability in an excavated crater.

(3) Areas that took excess amounts of time, and which were discussed previously include the removal of upheaved pavement, the hauling of select fill material and the anchoring of the mat. The construction of the mat took an excess amount of time, but this did not affect the total repair time.

4. LOAD TESTING, TEST 1-1

The load testing of the repair consisted of plate bearing tests on the subgrade, the finished base course (select fill) and the AM-2 surface, a special loading upon the floor of the apparent crater, and various testing utilizing an F-4 load cart upon the surface of the AM-2 matting. Locations of these tests and test types are shown in appendix IX. Table 5 demonstrates the relative compaction based on density.

Table 5

REPAIR DENSITIES AND MOISTURES, TEST 1-1

LOCATION	TEST	DENSITY	MOISTURE CONTENT
Compacted Debris	1	139.5	8.8
Top of Subgrade	2	139.6	8.1
	Average	139.6	8.4
Compacted Base	1	132.8	1.4
Course, Top	2	132.7	1.6
	Average	132.8	1.5

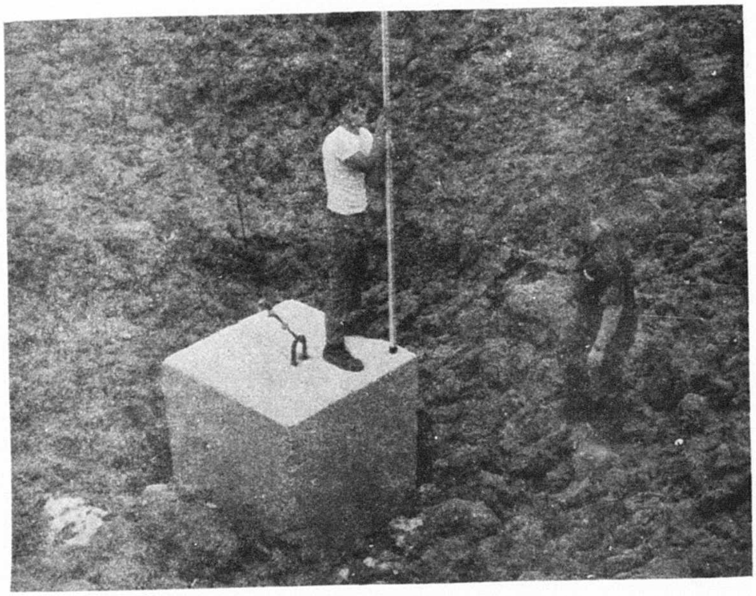
a. Apparent Crater Floor Loading.

This testing was accomplished by keeping time/deflection information on an 8,500 pound concrete block lowered to the crater floor with a 20-ton crane. Figure 24 shows the crater floor being leveled to accept the block. Following placement of the block, the survey team returned to take the time/settlement measurements with a rod and level. This method was used because of the inaccessibility of the crater floor to equipment required for more standard plate bearing tests. The load versus deflection curve for this test is shown in figure 25B. The data derived from this load testing provide input to the finite element code developed for AFWL by the Naval Civil Engineering Laboratory (NCEL) to analyze the stresses and strains within various backfill systems (refs. 16 and 17).

b. Subgrade Loading.

The subgrade loading, as was all plate loading, was performed by jacking against the beaver tail of a low boy trailer (figure 26). The trailer was backed into position unloaded on the completed repair (figure 27) to avoid loading the repair prior to actual plate loading. The loading was accomplished by adding weight to the trailer in the form of 4,000-pound concrete blocks. This was accomplished with either a 20-ton crane or a 745 loader.

A. Preparing Grade for Block Loading



B. Monitoring Test Block Penetration into Apparant Crater Floor

Figure 24. Test 1-1, Test of Crater Floor Material with 8,500 Pound Block

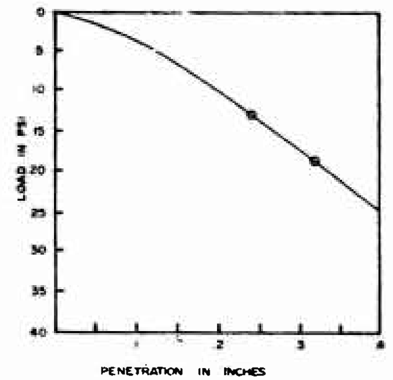
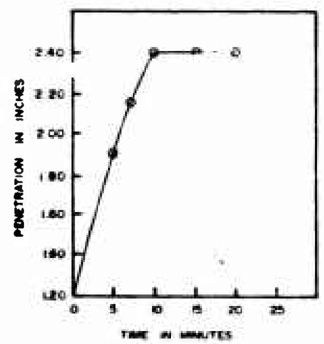


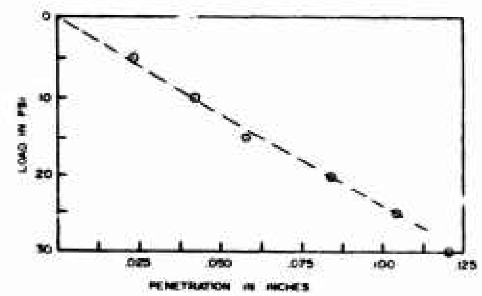
PLATE BEARING ON REPAIRED BC 30" PLATE

A



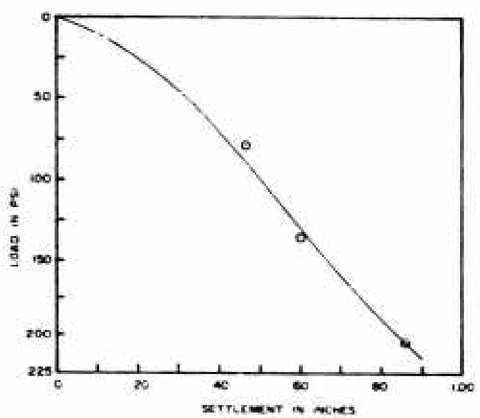
8500 LB BLOCK SETTLEMENT ON UNREPAIRED CRATER
LOAD = 4.62 PSI

B



BDR SUBGRADE $10\frac{1}{2}$" - PLATE BEARING ku = 225 (BEND CORR)

C



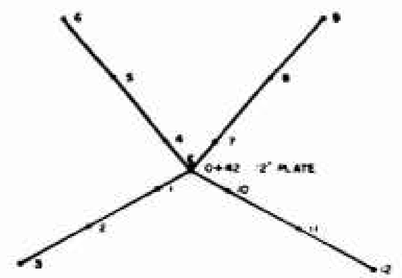
BDR AM-2 MATTING LOAD SETTLEMENT CURVE

D

E

LOAD SETTLEMENT ON AM-2

NOTE: WHEN CENTER OF AM-2 IS LOADED, EDGES BREAKS CONTACT WITH BASE COURSE



NOTE.
POSITIVE DEFLECTIONS ARE COMING UP
NEGATIVE DEFLECTIONS ARE GOING DOWN

STA	LOAD	DEF IN FEET
1	77.4 PSI (8,750 LBS)	+.015
2		+.020
3		+.010
4		+.006
5		+.017
6		+.009
7		+.01
8		+.001
9		+.007
10		+.016
11		-.006
12		.000
1	134.5 PSI (15,200 LBS)	+.019
2		+.022
3		+.011
4		-.004
5		+.018
6		+.016
7		+.012
8		+.008
9		+.008
10		+.022
11		-.006
12		-.009
1	203.5 PSI (23,000 LBS)	-.001
2		+.016
3		+.013
4		.000
5		+.012
6		+.013
7		+.022
8		+.007
9		+.012
10		+.018
11		+.003
12		-.001

Figure 25. Test 1-1, Plate Loading Deflection and Penetration Curves

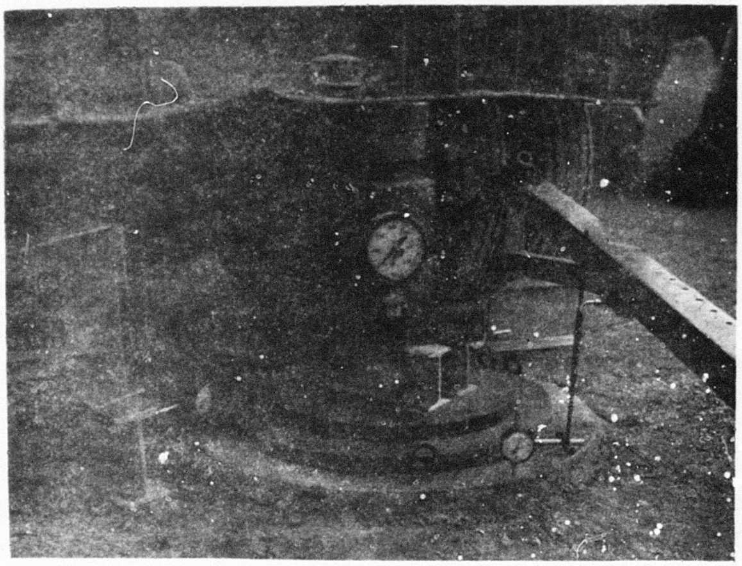


Figure 26. Completed AM-2 Airfield Patch prior to Load Testing

Figure 27. Plate Load Apparatus as used for all BDR Plate Bearing Tests

The subgrade loading was performed to provide input data for the backfill behavior code written by NCEL as well as to determine if the compaction effort applied to the debris backfill was adequate for expedient operation. The loading was accomplished with a 30-inch diameter plate, up to a maximum load of 49,000 pounds. A stiffness, K_u, of 244 pounds per cubic inch (PCI) was recorded, with the load versus penetration curve shown in figure 25C. This was a clay material at a moisture content of 6.7 percent, where the optimum moisture content was an average of about 11.4 percent, as shown in table 1, section II. However, the density of the compacted debris of 139 PCF, where the average optimum of the two clay layers is 119 PCF, indicates excellent debris compaction. This is especially true in view of the type of compaction used, i.e., a tracked dozer and rubber-tired loaders.

c. Base Course (Select Fill) Loading.

This load testing was conducted to provide parameter input for the NCEL code as well as to evaluate the acceptability of the compaction gained by the AFM 93-2 BDR technique. The performance of this material was very poor, with a stiffness value, K_u, of 54 PCI. The load versus penetration curve is shown in figure 25A. This testing, as was testing of the subgrade, was performed with a 30-inch diameter plate. Laboratory testing of the material showed the optimum density to be 136.3 PCF with a moisture content of 12.1 percent. However, a density of 143.1 to 150 PCF was easily reached when the material was used in the construction of the test site. The material placed in the repair had a density of 132.8 PCF with a moisture content of only 1.4 percent. Some of the poor performance could be attributed to the accidental use of a uniform aggregate by the BDR team; however, most of the deficiency is attributed to a lack of the proper equipment for compaction and the lack of moisture in the material.

d. AM-2 Repair Surface Loading.

(1) Plate Bearing Test

(a) A plate bearing test was run on the finished repair to both generate a load-settlement relationship and to analyze the deflection basin. Both of these items are desirable for checking outputs of the NCEL code. A 12-inch diameter plate was utilized, (area of 113 square inches), which approximated closely the 102-square-inch contact area of a main gear of the F-4E fighter aircraft (ref. 25). An attempt was made to put a total load of

50,000 pounds on the plate, thus simulating the high tire pressure of the F-4E aircraft and the total gross gear load of the F-111A aircraft. Figure 25D depicts the load-settlement curve, and demonstrates that nearly a 0.1-foot settlement was generated by a 220-PSI, 25,000-pound total, loading. This loading is less than the PSI loading of the F-4E aircraft (265 PSI) and the total one gear loading (47,000) of the F-11A aircraft as shown in reference 20.

(b) Figure 25E shows the deflection basin formed by the loaded plate. As can be seen, the AM-2 mat lifted off the base course at points surrounding the load due to the extreme deflection under the load plate.

(2) F-4 Load Cart.

Further testing was done with an F-4 load cart, shown being loaded in figure 28, with a main gear load of 29,000 pounds, exceeding the F-4E aircraft (one gear weight of 27,000 pounds) by 7 percent. Elevations were taken at 2-foot intervals on the mat at three different times as shown in figure 29. These points coincided approximately with the middle of each 2-foot mat section.

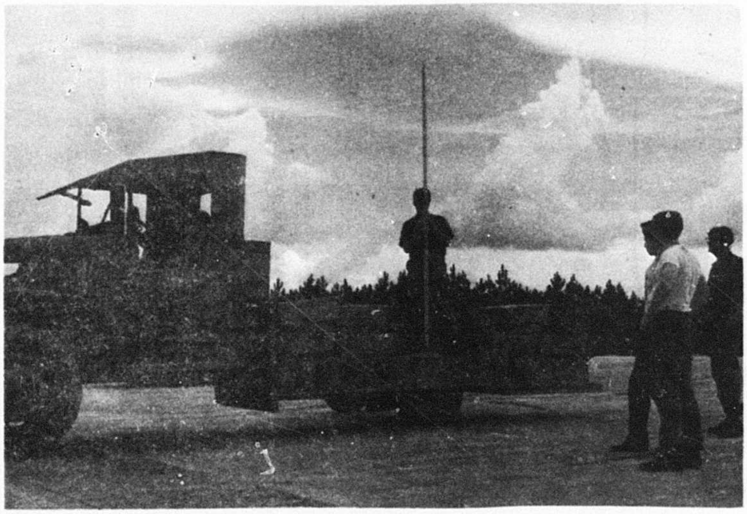
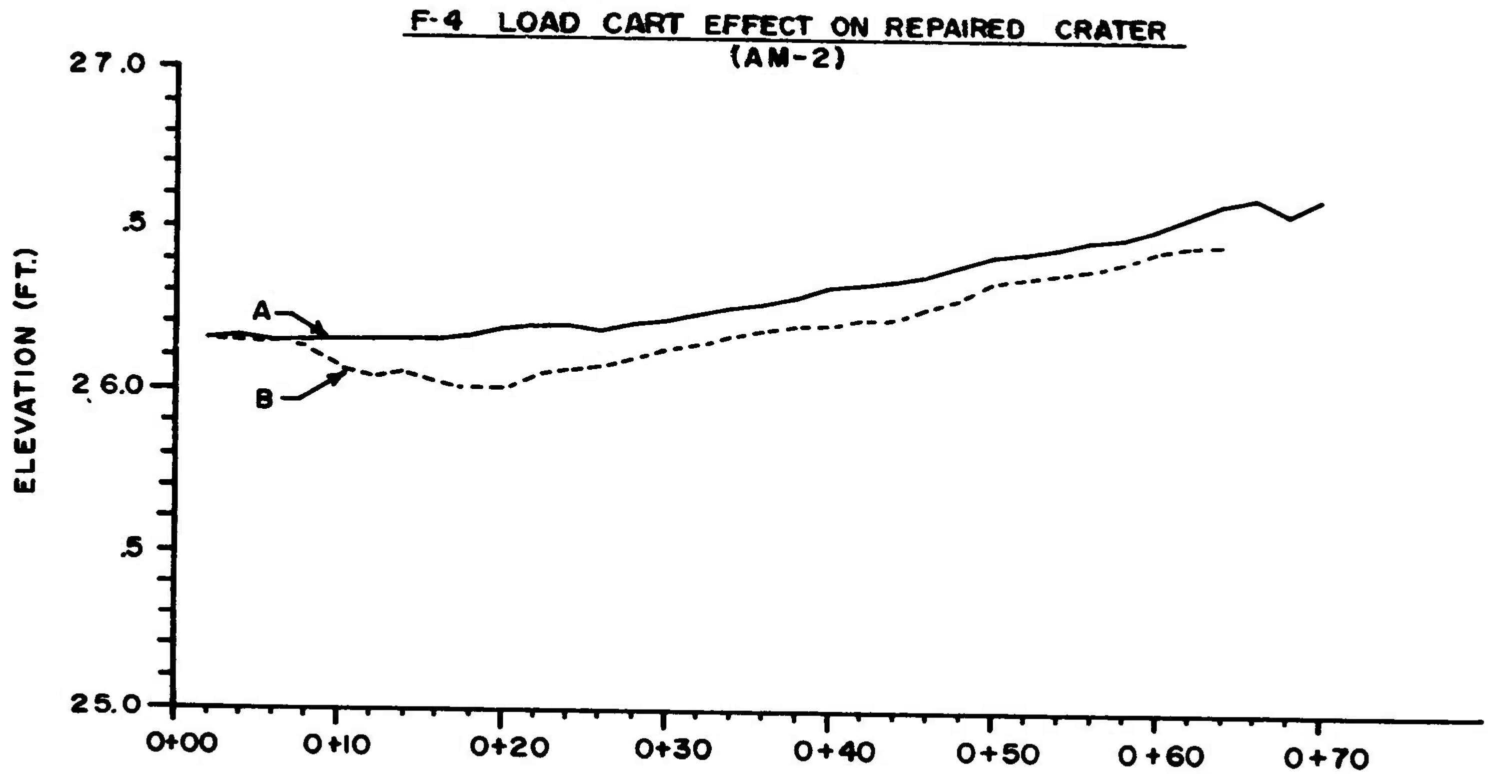


Figure 28. Test 1-1, F-4 Load Cart Loaded to 29,000 Pounds with Lead Ballast



NOTES:

LINE "A" REPRESENTS ORIGINAL PROFILE OF AM-2.
LINE "B" REPRESENTS PROFILE OF AM-2 AFTER THIRTY-ONE PASSES WITH F-4 LOAD CART WITH DATA POINTS STATICALLY LOADED AT TIME OF MEASUREMENT.

Figure 29. Test 1-1, Deflections of AM-2 Airfield Patch Surface Resulting from F-4 Load Cart Trafficking

The deflection recorded does not represent the maximum in the case of line C, where each point was loaded as the deflection was measured. Rotation of the sections of mat relative to each other caused an extreme concentrated load along the dedge of the mat panels abutting the joint. This deflection was extreme enough that a part of the load cart had to be removed to complete the testing (figure 30). The poor compaction of the base course, described above, is believed to be the cause of this problem.

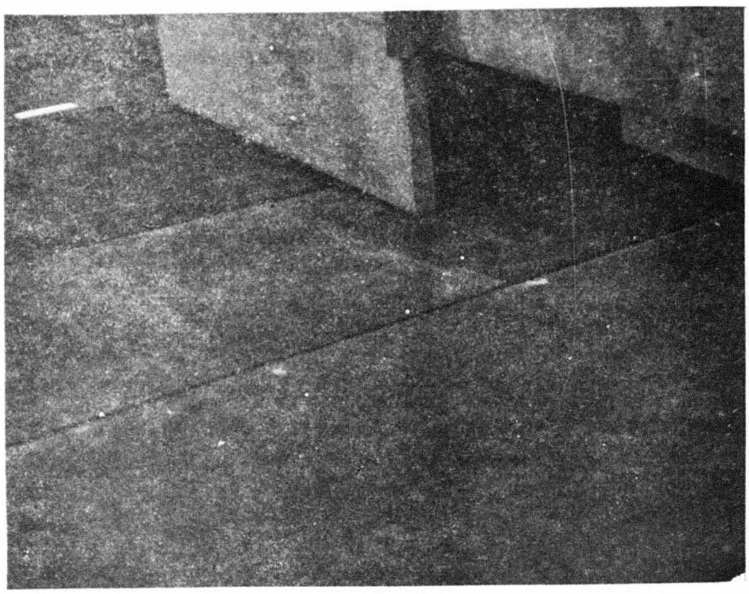


Figure 30. Test 1-1, F-4 Load Cart Hung Up on Excessive Deflection in AM-2 Airfield Patch

SECTION IV

TEST 1-2

1. OBJECTIVES

Objectives in three areas were met with information obtained from Test 1-2. The primary objective was the measurement of strains within a repaired crater backfill; specifically measurements were required in a repair similar in all respects to the type specified in AFM 93-2, and as accomplished in Test 1-1. Secondary objectives were the gathering of crater data and the testing of candidate BDR equipment on the upheaved crater lip.

a. Strain Measurement.

The measurement of strains was accomplished by utilizing Bison soil sensors placed in a clay soil column in the center of the crater repair during the repair process. These sensors were monitored on a Bison soil gage during backfilling and loading of the repair. The instrumentation plan is presented in appendix II.

b. Crater Data.

Crater data taken included, in addition to the items taken for Test 1-1, profiles to define the amount of pavement heave between the crater lip and the edge of the test pad. These were taken after careful removal of all ejecta, leaving only the upheaved pavement in place.

c. Equipment Performance.

Five types of equipment were tested in the cleaning of debris and removal of upheaved pavement. These were: the Allis-Chalmer 745 loader; the tri-pactor; a heavy vibrating compactor used in an attempt to force the upheaved area down; a backhoe mounted on an Allis-Chalmers 645 front loader; a 660 Gradall; and a Michigan 280 rubber-tired dozer. Also, a vibrating drum roller was tested for use in base course compaction.

2. INSTRUMENTATION AND LOAD TESTING

a. Instrumentation Procedure

(1) The instrumentation plan for Test 1-2 constitutes appendix II. The basic testing relies on the fact that the distance between two inductive

disks can be determined by measuring the electromagnetic coupling between them. In Test 1-2, the disks (sensors) were placed in a vertical column with the locations shown in figure 31 prior to loading. Careful attention was paid to ensuring that the center point of each sensor lay on the vertical axis of the crater. By strict adherence to this placement, distance measured between the sensors could be assumed to be a distance along the vertical axis.

(2) The sensors were carefully bedded in Ottawa sand (figure 32) and the space between the sensors was filled with clean rubble-free clay taken from the subgrade of the test section. The sensors thus were in a vertical column of clay within the crater repair. This was necessary to ensure a continuity of nonconductive material between the sensors and to prevent damage to the sensors.

(3) The sensors were monitored with the use of a Bison strain gage console. The gage was used in conjunction with a digital volt meter and a specially designed BDR switch box constructed at AFWL. This box provided for the reading of all 18 sensor pairs in a short amount of time. The strain gage console displaced a digital readout which was reduced to zero before a reading was taken from the digital volt meter. The instrumentation is seen in figure 33.

b. Backfilling and Sensor Placement

(1) The process for backfilling began by excavating to the true floor of the crater. The true floor was in ground water, however, the sensors were designed to withstand 6 psi water immersion for a period of 24 hours. Additional water proofing was added during calibration. The first sensor was placed in the sand below the true crater floor. It was assumed that this lowest point had not moved significantly during the cratering event and would not move significantly, and so could provide a datum for the vertical gage line. This assumption was later determined to be invalid. Sensors were then placed at 6-inch intervals within the fallback material in an attempt to accurately describe the interfaces between the fallback and true crater floor and the fallback and the apparent crater. Above this region, sensors were placed at approximately 12-inch intervals until the interface between the subgrade or crater backfill and the base course was reached, at which point the sensors were once again placed at 6-inch intervals.

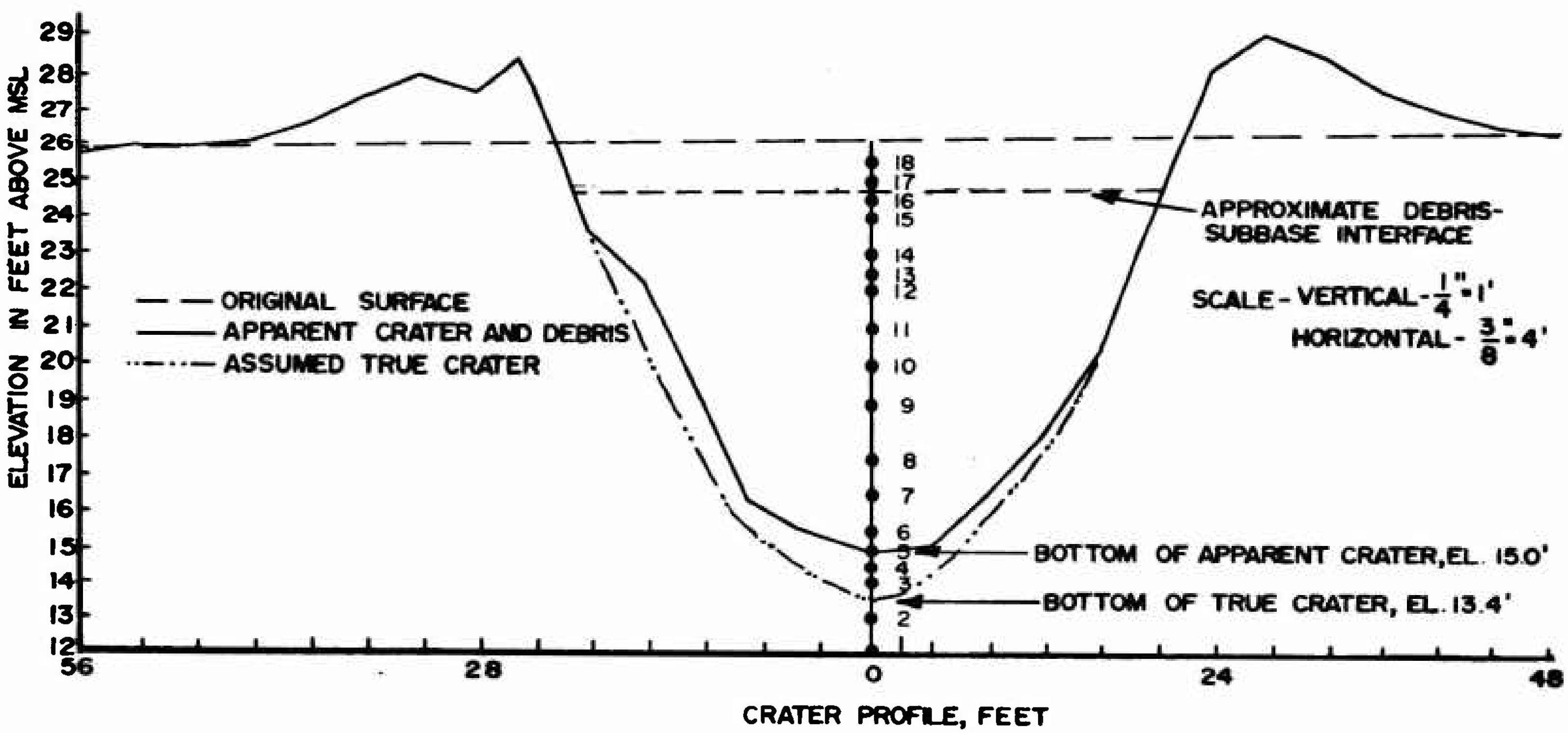


Figure 31. Test 1-2, Location of Bison Sensors as Placed

Figure 32. Test 1-2, Bison Sensor Being Imbedded in Ottawa Sand

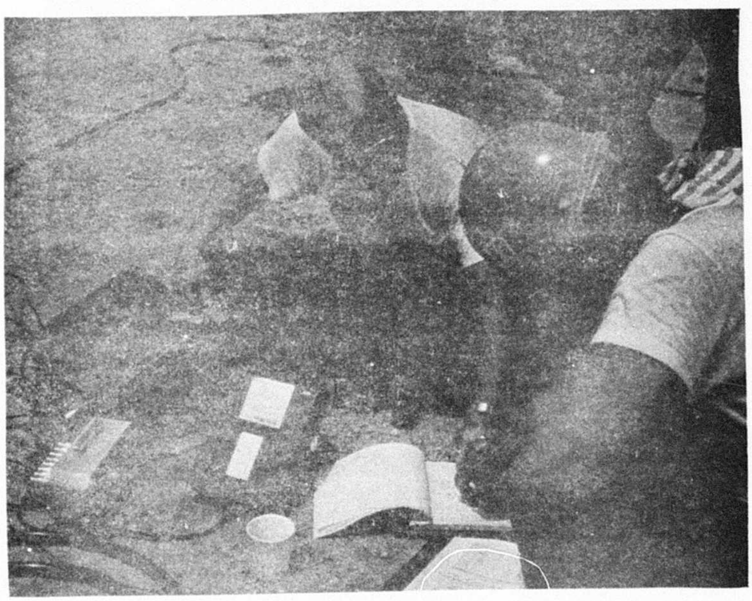


Figure 33. Test 1-2, Bison Guage Data Recording and Monitoring Equipment

(2) The backfilling process above the floor of the apparent crater consisted of backfilling approximately 3 feet around a large cylindrical tube. The tube was then removed and the cylindrical hole remaining was used to place two to three sensors and the clay column in which they were contained. This process was repeated several times, as seen in figures 34A, B and C. This left the sensors in the desired clay column surrounded by the ordinary backfill ejecta material.

(3) This method relied on the assumption that if the cross sectional area of the column of clay in which the sensors are located is small in comparison to the total backfill surface area, the settlement of the column will be similar to the settlement of the surrounding backfill. Additionally, the clay column was assumed to have very little effect on the settlement of the soil mass.

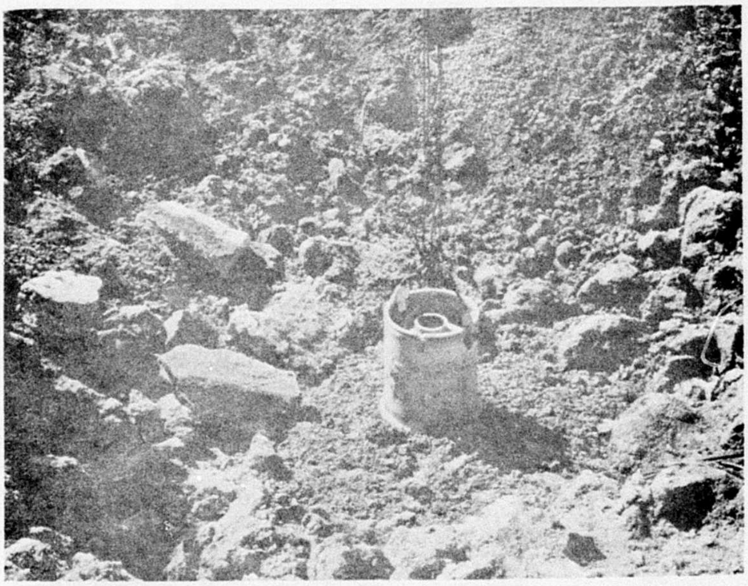


Figure 34A. Test 1-2, Backfilling Procedure Utilizing Cylinder to Form Column for Sensors

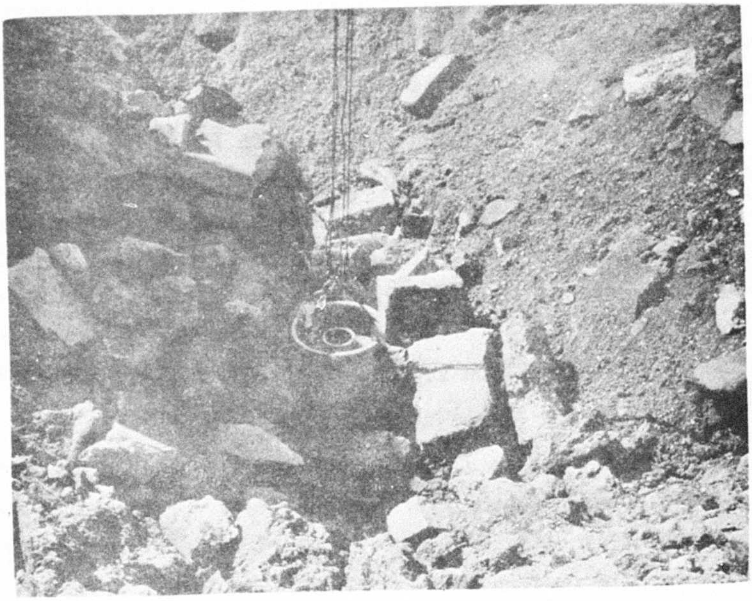


Figure 34B. Test 1-2, Backfilling Procedure Utilizing Cylinder to Form Column for Sensors

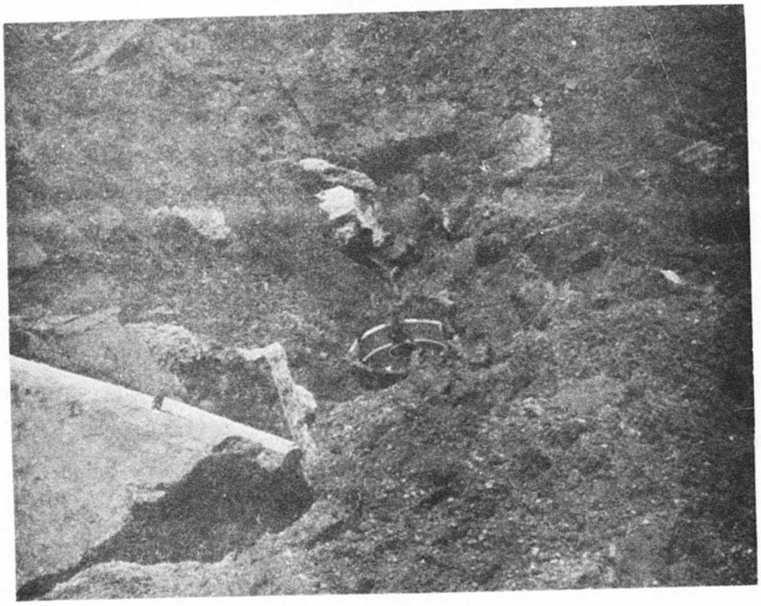


Figure 34C. Test 1-2, Backfilling Procedure Utilizing Cylinder to Form Column for Sensors

(4) Because the additional backfill as the crater was repaired constituted a surcharge on the earlier backfill, the gages were monitored as new lifts of material were added. The readings are contained in table 6 and show essentially the settlement resulting from the surcharge.

(5) It should be noted that the compaction for this test was poorer in the lower areas of the crater due to the care that had been taken to protect the sensors, and that the horizontal cross sectional area of column of clay could not be accurately controlled and so varied. Densities and moistures around all sensors are given in table 7. The west side of the repair also suffered from a lack of compaction due to the care taken not to damage signal lines from the Bison sensors to the Bison gage, although the gage lines were protected by plastic tubing, figure 35A and B.

c. Measured Strain. Tables 8 and 9 show the elevation of each sensor pair and the strain between sensor pairs respectively. Figure 36 shows the location of sensors at significant times. Several factors require explanation. The strain in table 9 is referenced to three different initial states. First, the strain is calculated upon completion of backfilling with reference to the surveyed location of each sensor during backfilling. The strain calculated in this manner and shown in figure 37 represents the amount of strains resulting from the backfilling operation. As can be seen, the nonhomogeneous nature of the backfill and the lack of compaction in the lower portion of the crater led to significant strain situations. An example is the 31 percent tensile strain recorded in the interval between sensors 8 and 9. A portion of this tensile strain can be attributed to the consolidation of the gray sand strata underlaying the crater. The regions showing the tensile strain are confined to the areas in which large amounts of concrete debris were placed, similar to that pictured in figure 34B. This factor may also be involved in the explanation of the resulting strain. The strain prior to loading as based on the sensor location following the completion of backfilling is also shown in figure 37. This strain resulted from the necessity to delay work over a 3-day weekend. Several inches of rain fell on the site during that time, and even though the repair area was covered by AM-2 matting, the backfill was saturated. A measured deflection due to consolidation of 0.18-foot within the crater backfill resulted. Sensor 1 very possible also moved downward, resulting in a 6 to 7-inch surface deflection (figure 38). This amount of consolidation could not have been tolerated by a rigid pavement. Although

Table 6

TEST 1-2, SEPARATION OF SENSOR PAIRS
PRE-LOAD READINGS

SENSOR PAIR NUMBERS	SURVEYED DISTANCE BETWEEN SENSORS (S)	24 MAY AFTER AGGREGATE BACKFILL (1)	25 MAY BEGINNING OF DAY (2)	25 MAY GRADING AND COMPACTION (3)	25 MAY FINAL COMPACTING (4)	25 MAY AM-2 MATTING IN PLACE (5)	26 MAY 1300 HRS NO LOAD (6)	27 MAY 1300 HRS NO LOAD (7)	28 MAY 1300 HRS NO LOAD (8)	29 MAY 0830 HRS AM-2 REMOVED (9)	29 MAY MORE AGGREGATE RECOMPACTION (10)
1-2	11-7/8	10.88	10.87	10.87	10.87	10.87	10.88	10.85	10.89	10.85*	10.85*
2-3	12	11.23	11.23	11.23	11.13	11.23	11.24	11.20	11.21	[illegible]	11.15
3-4	6-1/8	6.31	6.31	6.31	6.31	6.31	6.31	6.03	6.02	6.00	5.98
4-5	6	5.60	5.60	5.59	5.59	5.59	5.55	5.08	5.06	5.05	5.05
5-6	6	5.79	5.79	5.79	5.79	5.79	5.73	5.30	5.28	5.27	5.26
6-7	12	13.56*	13.57*	13.57*	13.57*	13.57*	13.33*	12.51	12.52	12.43	12.42
7-8	12-1/8	12.15	12.06	12.05	12.05	12.05	11.97	11.18	11.10	11.05	11.02
8-9	12	15.80x	15.82x	15.81x	15.81x	15.81x	15.72x	15.40x	15.46x	15.32x	15.32x
9-10	11-7/8	11.56	11.56	11.55	11.56	11.56	11.40	11.14	11.08	11.03	11.02
10-11	12-1/8	13.80x	13.81x	13.77x	13.77x	13.78x	13.61x	13.35x	13.34	13.10	12.93
11-12	12-1/8	11.70	11.70	11.49	11.33	11.33	11.32	11.24	11.15	11.02	10.92
12-13	5-7/8	5.64	5.64	5.34	5.34	5.34	5.36	5.34	5.33	5.32	5.28
13-14	6	5.86	5.86	5.84	5.86	5.77	5.85	5.83	5.83	5.82	5.81
14-15	13-1/8	13.11	13.10	13.03	13.01	13.05	13.15	13.10	13.13	13.02	12.93
15-16	6	5.28	5.27	5.26	5.26	5.26	5.29	5.29	5.28	5.27	5.26
16-17	6	5.95	5.91	5.87	5.87	5.87	5.90	5.90	5.90	5.90	5.88
17-18	6-5/8	6.58	6.58	6.42	6.40	6.43	6.54	6.53	6.54	6.52	6.45

Table 6 (Continued)

29 MAY

SENSOR PAIR NUMBERS	AM-2 MATTING REPLACED (11)	10,000 LB LOAD (12)	18,250 LB LOAD (13)	25,600 LB LOAD (14)	32,000 LB LOAD (15)	40,700 LB LOAD (16)	49,900 LB LOAD (17)	LOAD REMOVED (18)	LOAD CART (19) AFTER 6TH PASS	LOAD CART (20) AFTER 11TH PASS	LOAD CART (21) AFTER 21ST PASS	LOAD CART (22) AFTER 31ST PASS
1-2	10.85*	10.85*	10.85*	10.84*	10.84*	10.84*	10.84*	10.89*	10.84*	10.83*	10.83*	10.83*
2-3	11.15	11.15	11.15	11.15	11.15	11.15	11.15	11.14	11.14	11.14	11.14	11.14
3-4	5.99	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98	5.98
4-5	5.05	5.05	5.05	5.05	5.05	5.05	5.05	5.05	5.05	5.05	5.05	5.05
5-6	5.27	5.27	5.27	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26	5.26
6-7	12.41	12.41	12.41	12.41	12.41	12.41	12.40	12.38	12.38	12.38	12.38	12.38
7-8	11.01	11.01	11.00	11.00	11.00	11.00	10.99	10.98	10.98	10.98	10.98	10.98
8-9	15.31x	15.31x	15.30x	15.31x	15.30x	15.30x	15.30x	15.29x	15.29x	15.29x	15.31x	15.30x
9-10	11.01	11.01	11.00	11.00	10.99	10.96	10.96	10.96	10.96	10.96	10.95	10.95
10-11	12.93	12.91	12.91	12.91	12.88	12.83	12.77	12.77	12.75	12.75	12.74	12.73
11-12	10.92*	10.91*	10.90*	10.89*	10.88*	10.84*	10.78*	10.78*	10.76*	10.75*	10.74*	10.73*
12-13	5.28	5.28	5.28	5.27	5.27	5.26	5.22	5.22	5.21	5.21	5.20	5.19
13-14	5.81	5.81	5.80	5.80	5.79	5.78	5.76	5.76	5.75	5.75	5.75	5.75
14-15	13.01	13.00	12.99	12.98	12.97	12.96	12.93	12.93	12.92	12.92	12.90	12.89
15-16	5.26	5.26	5.26	5.26	5.26	5.25	5.25	5.25	5.24	5.24	5.24	5.24
16-17	5.87	5.87	5.86	5.86	5.86	5.86	5.85	5.85	5.85	5.85	5.84	5.84
17-18	6.46	6.46	6.45	6.45	6.44	6.44	6.43	6.43	6.42	6.42	6.42	6.41

* Indicates values were determined by extrapolation of calibration curve.

x These values were taken from calibration curves of sensor pairs 20-21 and 23-24 which were taken over greater separation distances and are very close to pairs 8-9 and 10-11 respectively.

Table 7

TEST 1-2, DENSITY AND MOISTURE NEAR SENSORS

Sensor #	DENSITY, PCF	MOISTURE CONTENT, %
1	108.2-111.3	16.4-16.8
2-7	108.8	12.8
8-10	106.9	[illegible].5
11	unknown	6.9
12	unknown	9.2
13-17	98.4	4.5
18	140.9	7.5

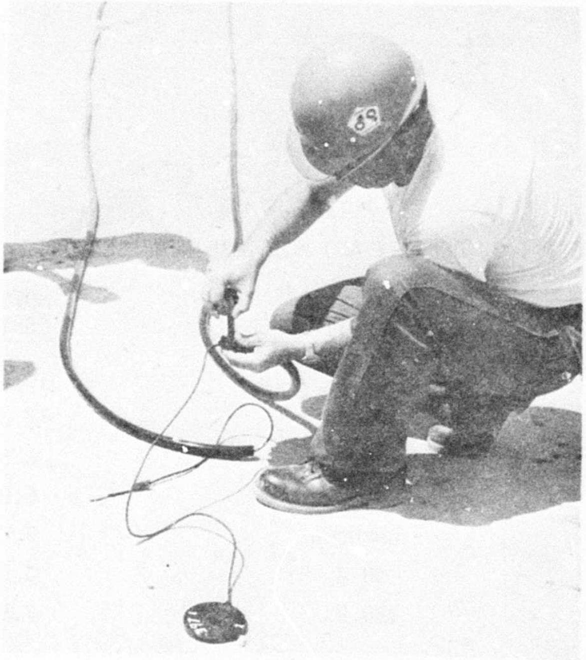


Figure 35A

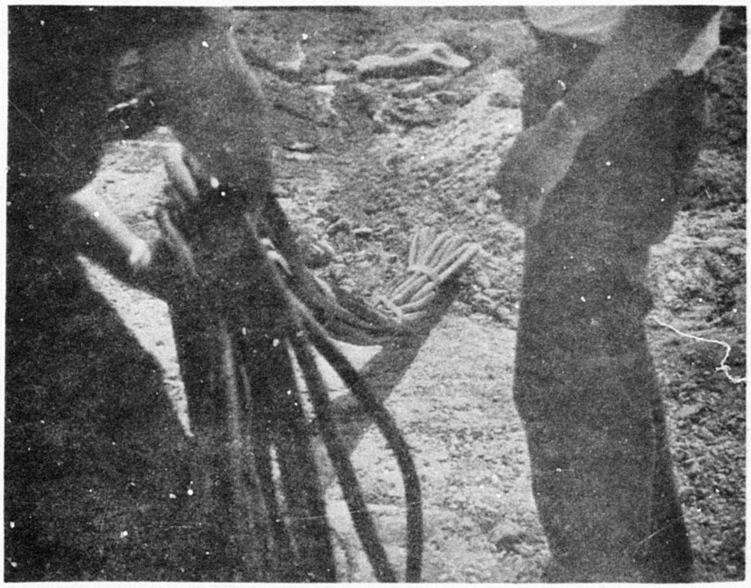


Figure 35B

Figure 35. Test 1-2, Plastic Tubing Used to Protect Signal Lines

Table 8

TEST 1-2, ELEVATIONS OF SENSORS AT SELECTED TIMES

SENSOR NUMBER	AFTER AGGREGATE BACKFILL (1)	BEGINNING OF DAY (2)	GRADING AND COMPACTION (3)	FINAL COMPACTING (4)	AM-2 MATTING IN PLACE(5)	26 MAY 1300 HRS(6) NO LOAD	27 MAY 1300 HRS(7) NO LOAD	28 MAY 1300 HRS(8) NO LOAD	29 MAY 0830 HRS(9) AM-2 REMOVED	29 MAY MORE AGGREGATE AND RECOMPACTION (10)	29 MAY AM-2 MATTING REPLACED (11)
1	145.88	145.88	145.88	145.88	145.88	145.88	145.88	145.88	145.88	145.88	145.88
2	156.76	156.75	156.75	156.75	156.75	156.76	156.73	156.77	156.73	156.73	156.73
3	167.99	167.98	167.98	167.88	167.98	168.00	167.93	167.98	167.90	167.88	167.88
4	174.30	174.29	174.29	174.19	174.29	174.31	173.96	174.00	173.90	173.86	173.87
5	179.90	179.89	179.88	179.78	179.88	179.86	179.04	179.06	178.95	178.91	178.92
6	185.69	185.68	185.67	185.57	185.67	185.59	184.34	184.34	184.22	184.17	184.19
7	199.25	199.25	199.24	199.14	199.24	198.92	196.85	196.86	196.65	196.59	196.60
8	211.40	211.31	211.29	211.19	211.29	210.89	208.03	207.96	207.70	207.61	207.61
9	227.20	227.13	227.10	227.00	227.10	226.61	223.43	223.42	223.02	222.93	222.92
10	238.76	238.69	238.65	238.56	238.66	238.01	234.57	234.50	234.05	233.95	233.93
11	252.56	252.50	252.42	252.33	252.44	251.62	247.92	247.84	247.15	246.88	246.86
12	264.26	264.20	263.91	263.66	263.77	262.94	259.16	258.99	258.17	257.80	257.78
13	269.40	269.84	269.25	269.00	269.11	268.30	264.50	264.32	263.49	263.08	263.06
14	275.76	275.70	275.09	274.86	274.88	274.15	270.33	270.15	269.31	268.89	268.87
15	288.87	288.80	288.12	287.87	287.93	287.30	283.43	283.28	282.33	281.82	281.88
16	294.15	294.07	293.38	293.13	293.16	292.59	288.72	288.56	287.60	287.08	287.14
17	300.10	299.98	299.25	299.00	299.06	298.49	294.62	294.46	293.50	292.96	293.01
18	306.68	306.56	305.67	305.40	305.49	305.03	301.15	301.00	300.02	299.41	299.47

Table 8 (Continued)

SENSOR NUMBER	29 MAY 10,000 LB LOAD (12)	29 MAY 18,250 LB LOAD (13)	29 MAY 25,600 LB LOAD (14)	29 MAY 32,000 LB LOAD (15)	29 MAY 40,700 LB LOAD (16)	29 MAY 49,900 LB LOAD (17)	29 MAY LOAD (18) REMOVED	LOAD CART AFTER 6TH PASS (19)	LOAD CART AFTER 11TH PASS (20)	LOAD CART AFTER 21ST PASS (21)	LOAD CART AFTER 31ST PASS (22)
1	145.88	145.88	145.88	145.88	145.88	145.88	145.88	145.88	145.88	145.88	145.88
2	156.73	156.73	156.72	156.72	156.72	156.72	156.72	156.72	156.71	156.71	156.71
3	167.88	167.88	167.87	167.87	167.87	167.87	167.91	167.86	167.85	167.85	167.85
4	173.86	173.86	173.88	173.85	173.85	173.85	173.89	173.84	173.83	173.83	173.83
5	178.91	178.91	178.90	178.90	178.90	178.90	178.94	178.89	178.88	178.88	178.88
6	184.18	184.18	184.16	184.16	184.16	184.16	184.20	184.15	184.14	184.14	184.14
7	196.59	196.59	196.57	196.57	196.57	196.56	196.58	196.53	196.52	196.52	196.52
8	207.60	207.59	207.57	207.57	207.57	207.55	207.56	207.51	207.50	207.50	207.50
9	222.91	222.89	222.88	222.87	222.87	222.85	222.85	222.80	222.79	222.81	222.80
10	233.92	233.89	233.88	233.86	233.83	233.81	233.81	233.76	233.75	233.76	233.75
11	246.83	246.80	246.79	246.74	246.66	246.58	246.58	246.51	246.50	246.50	246.30
12	257.74	257.70	257.68	257.62	257.50	257.36	257.36	257.27	257.25	257.24	257.21
13	263.02	262.98	262.95	262.89	262.76	262.58	262.58	262.48	262.46	262.44	262.40
14	268.83	268.78	268.75	268.68	268.54	268.34	268.34	268.23	268.21	268.19	268.15
15	281.83	281.77	281.73	281.65	281.50	281.27	281.27	281.15	281.13	281.09	281.04
16	287.09	287.03	286.99	286.91	286.75	286.52	286.52	286.39	286.37	286.33	286.28
17	292.96	292.89	292.85	292.77	292.61	292.37	292.37	292.24	292.22	292.17	292.12
18	299.42	299.34	299.30	299.21	299.05	298.80	298.80	298.66	298.64	298.59	298.53

Table 9

TEST 1-2, STRAIN BETWEEN SENSOR PAIRS AT SELECTED TIMES

SENSOR PAIR NUMBERS	24 MAY S-1* (1) AFTER AGGREGATE BACKFILL	25 MAY 1-2* (2) BEGINNING OF DAY	25 MAY 1-3* (3) GRADING AND COMPACTION	25 MAY 1-4* (4) FINAL COMPACTING	25 MAY 1-5* (5) AM-2 MATTING IN PLACE	26 MAY 1-6* (6) 1300 HRS NO LOAD	27 MAY 1-7* (7) 1300 HRS NO LOAD	28 MAY 1-8* (8) 1300 HRS NO LOAD	29 MAY 1-9* (9) 0830 HRS AM-2 REMOVED	29 MAY 1-10* (10) MORE AGGREGATE RECOMPACTION	29 MAY 1-11* (11) AM-2 MATTING REPLACED
1-2	-8.38	-.09	-.09	-.09	-.09	0	-.28	+.09	-.28	-.28	-.28
2-3	-6.42	0	0	-.89	0	+.08	-.27	-.18	-.53	-.71	-.71
3-4	+3.02	0	0	0	0	0	-4.44	-4.60	-4.91	-5.23	-5.07
4-5	-6.67	0	-.18	-.18	-.18	-.89	-9.29	-9.64	-9.82	-9.82	-9.82
5-6	-3.50	0	0	0	0	-1.04	-8.46	-8.81	-8.98	-9.15	-8.38
6-7	+13.00	+.07	+.07	+.07	+.07	-1.70	-7.74	-7.67	-8.33	-8.41	-8.48
7-8	+0.21	-.74	-.82	-.82	-.82	-1.48	-7.98	-8.64	-9.05	-9.30	-9.38
8-9	+31.67	+.10	+.06	+.06	+.06	-.51	-2.53	-2.15	-3.04	-3.04*	-3.10
9-10	-2.65	0	-.09	0	0	-1.38	-3.63	-4.15	-4.58	-4.67	-4.76
10-11	+13.81	+.07	-.22	-.22	-.14	-1.38	-3.26	-3.33	-5.07	-6.30	-6.30
11-12	-3.51	0	-1.79	-3.16	-3.16	-3.25	-3.93	-4.70	-5.81	-6.67	-6.67
12-13	-4.00	0	-5.32	-5.32	-5.32	-4.96	-5.32	-5.50	-5.67	-6.38	-6.38
13-14	-2.33	0	-.34	0	-1.54	-.17	-.51	-.51	-.68	-.85	-.85
14-15	-.11	-.07	-.61	-.76	-.46	+.31	-.08	+.15	-.69	-1.37	-.76
15-16	-12.00	-.19	-.38	-.38	-.38	+.19	+.19	0	-.19	-.38	-.38
16-17	-.83	-.67	-1.34	-1.34	-1.34	-.84	-.84	-.84	-.84	-1.18	-1.34
17-18	-.68	0	-2.43	-2.74	-2.28	-.61	-.76	-.61	-.91	-1.98	-1.82

Table 9 (Continued)

29 May

SENSOR PAIR NUMBERS	11-12* (12) 10,000 LB LOAD	11-13* (13) 18,250 LB LOAD	11-14* (14) 25,600 LB LOAD	11-15* (15) 32,000 LB LOAD	11-16* (16) 40,700 LB LOAD	11-17* (17) 49,900 LB LOAD	11-18* (18) LOAD REMOVED	11-19* (19) LOAD CART AFTER 6TH PASS	11-20* (20) LOAD CART AFTER 11TH PASS	11-21* (21) LOAD CART AFTER 21ST PASS	11-22* (22) LOAD CART AFTER 31ST PASS
1-2	0	0	-.92	-.92	-.92	-.92	+.37	-.92	-.18	-.18	-.18
2-3	0	0	0	0	0	0	-.90	-.90	-.90	-.90	-.90
3-4	-.17	-.17	-.17	-.17	-.17	-.17	-.17	-.17	-.17	-.17	-.17
4-5	0	0	0	0	0	0	0	0	0	0	0
5-6	0	0	-.19	-.19	-.19	-.19	-.19	-.19	-.19	-.19	-.19
6-7	0	0	0	0	0	-.08	-.24	-.24	-.24	-.24	-.24
7-8	0	-.09	-.09	-.09	-.09	-.18	-.27	-.27	-.27	-.27	-.27
8-9	0	-.06	0	-.06	-.06	-.06	-.13	-.13	-.13	0	-.06
9-10	0	-.09	-.09	-.18	-.45	-.45	-.45	-.45	-.45	-.54	-.54
10-11	-.15	-.15	-.15	-.33	-.77	-1.24	-1.24	-1.39	-1.39	-1.47	-1.55
11-12	-.09	-.18	-.27	-.37	-.73	-1.28	-1.28	-1.46	-1.56	-1.65	-1.74
12-13	0	0	-.19	-.19	-.38	-1.14	-1.14	-1.33	-1.33	-1.52	-1.70
13-14	0	-.17	-.17	-.34	-.52	-.86	-.86	-1.03	-1.03	-1.03	-1.03
14-15	-.08	-.15	-.23	-.31	-.38	-.61	-.61	-.69	-.69	-.85	-.92
15-16	0	0	0	0	-.19	-.19	-.19	-.38	-.38	-.38	-.38
16-17	0	-.17	-.17	-.17	-.17	-.34	-.34	-.34	-.34	-.51	-.51
17-18	0	-.15	-.15	-.31	-.31	-.46	-.46	-.62	-.62	-.62	-.77

$\% \text{ Strain} = \frac{\Delta L}{L_B}$

L_B = Original Length at Reading B

ΔL = Change in Length

* = First Digit Indicates Reference Sensor Location, Second Digit Indicates Strain Event.

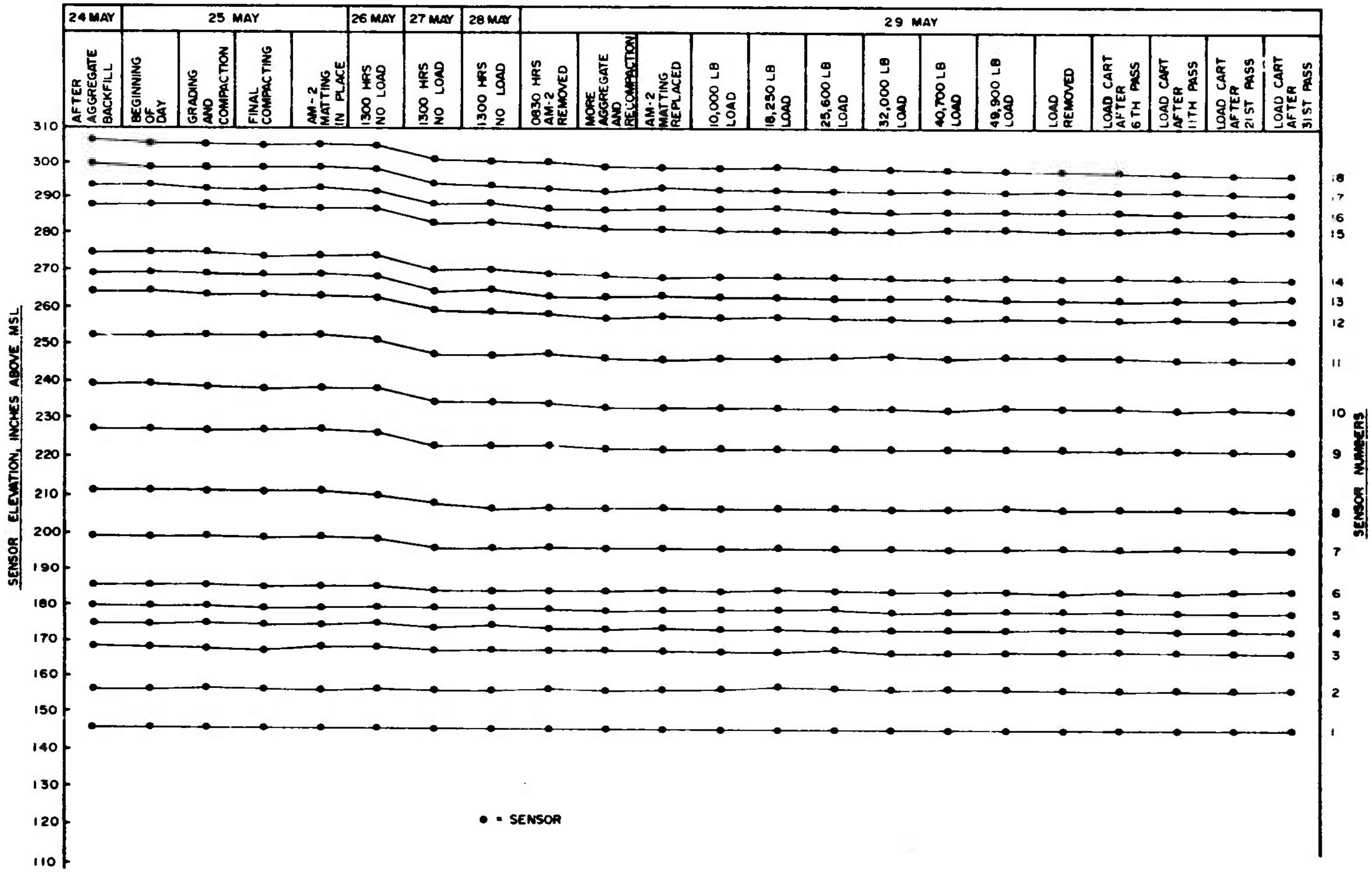


Figure 36. Test 1-2, Sensor Locations at Significant Times

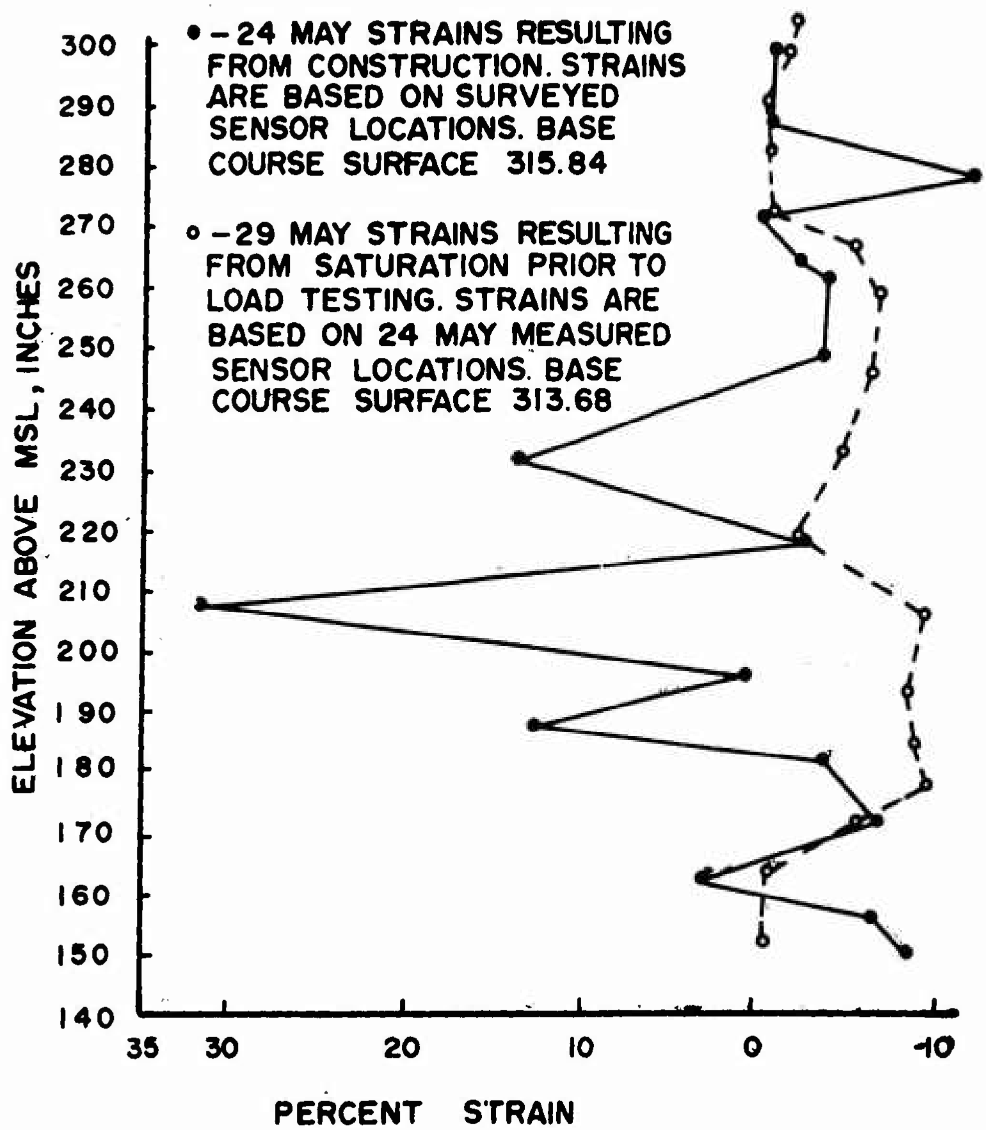


Figure 37. Test 1-2, Construction and Saturation Strains and Consolidation

some systems other than AM-2 would initially keep moisture out of the backfill material, the presence of high water tables could result in this type consolidation.

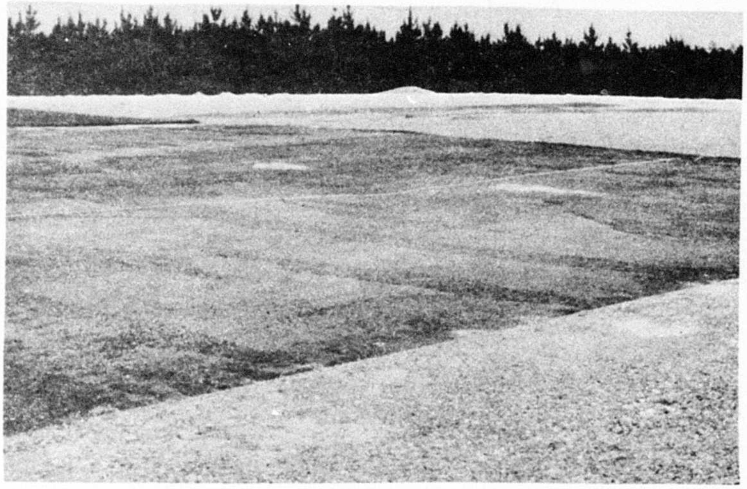


Figure 38. Test 1-2, Repaired Base Course Deflection Following Heavy Rains during a Three Day Period

d. Load Testing

(1) Load testing of the crater was begun after the base course was regraded and compacted to give an acceptable repair grade. Figure 39 shows the surface penetration resulting from loadings on the AM-2 matting. Load penetration relations for the subbase and compacted debris are also shown. In the latter cases, a 30-inch diameter plate for standardized testing was utilized. Loading on the AM-2 was accomplished with a 12-inch diameter plate to simulate an F-4C wheel load.

(2) Figure 40 defines the settlement basin, yielding information for input into the NCEL program. Figure 41 details the settlement induced by passing the load cart over the repair 31 times at a gross load of 29,000 pounds. The profile of the repair section centerline is shown before load cart testing and after the 31st pass in figure 42. Figure 43 shows the strains resulting from three different loading conditions. The loading sequence on the AM-2 mat was an increase of static load from 0 to 49,990 pounds in increments shown in table 9, followed by removal of the static

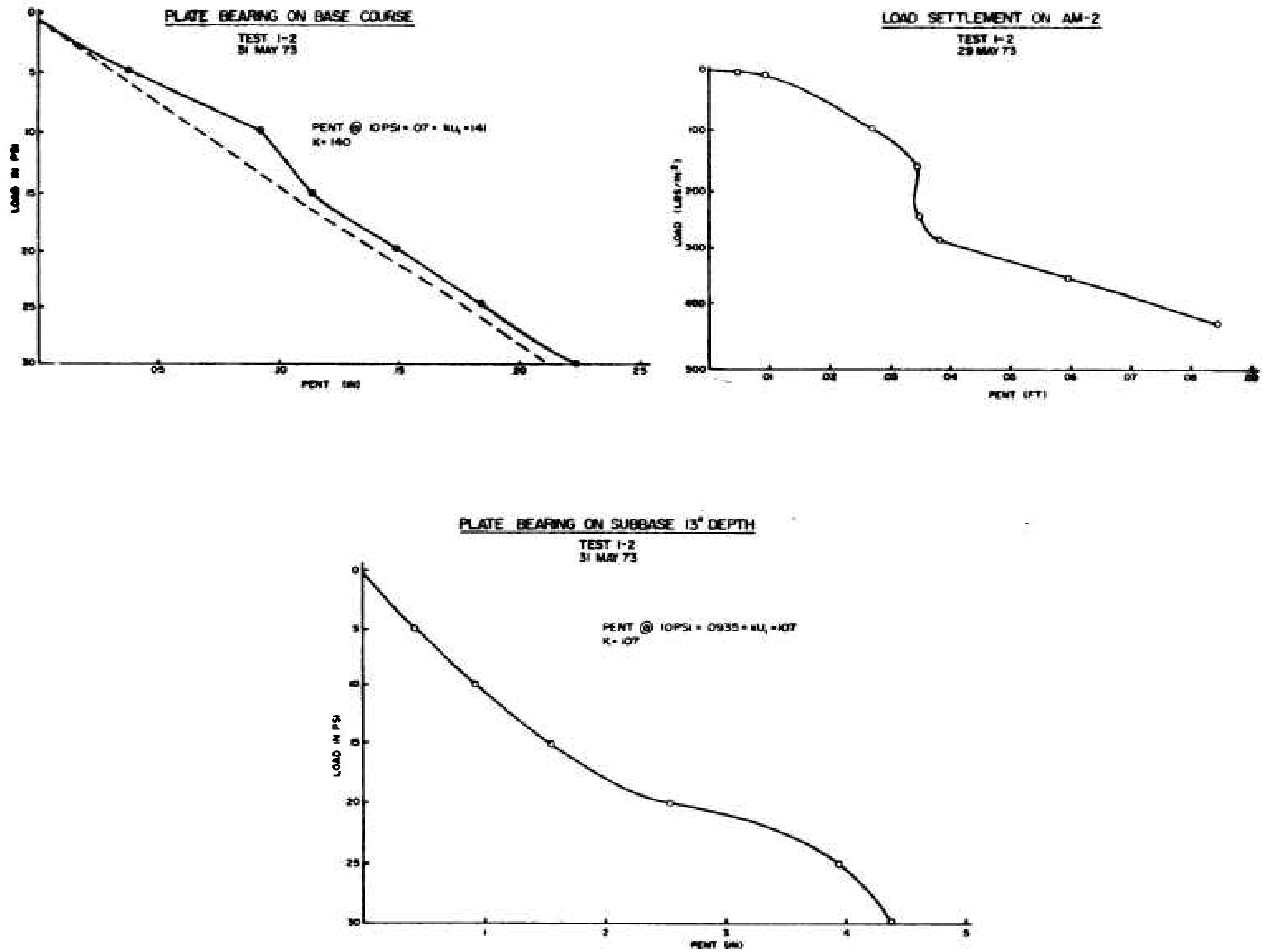
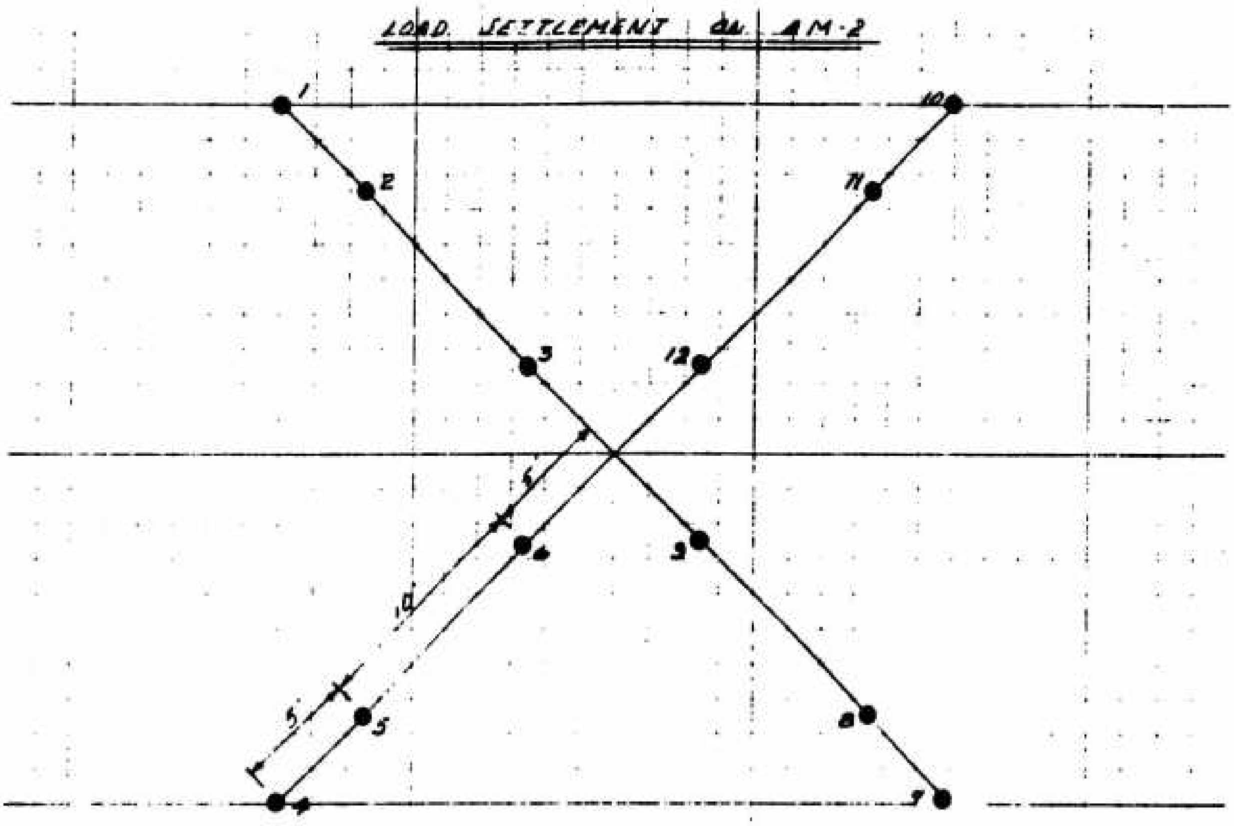


Figure 39. Test 1-2, Plate Loading Test Penetration Curve



STA. DEFORMATION IN FEET.

STA.	101 PSI	161 PSI	244 PSI	284 PSI	356 PSI	432 PSI
1	-.008	-.023	+.002	+.001	+.002	-.005
2	-.005	-.008	+.001	-.003	.000	.000
3						
4	-.004	-.009	-.002	.000	+.001	-.020
5	-.002	-.009	-.003	+.001	+.004	-.002
6	-.008	-.010	-.009	-.007	-.006	-.014
7	-.002	-.014	-.001	+.002	+.002	+.001
8	-.002	-.011	-.002	-.004	.000	-.003
9	-.003	.005	+.008	+.015	.000	-.011
10	-.007	-.009	-.004	-.008	.000	+.002
11	-.003	-.004	-.008	-.008	+.001	+.003
12	-.005	-.005	-.003	+.004	-.004	.000

Figure 40. Test 1-2, Deflection Basin Study on AM-2 Airfield Patch Repair

	BDR TEST NR. 2 CENTERLINE PROFILE DATA								
STATION	ELEVATIONS (ft)								
	AC BEFORE/AFTER TEST	BASE COURSE BEFORE/AFTER TEST	AM-2 MAT						
			BEFORE F-4 CART	DURING 6TH PASS	11TH PASS	21ST PASS	31ST PASS		
0 + 00	[illegible] / 25.98	— —	—	—	—	—	—		
0 + 02	26.00 / 26.00	— —	26.15	26.15	26.15	26.15	26.15		
0 + 04	26.01 / 26.00	— —	26.16	26.15	26.15	26.15	26.15		
0 + 06	26.00 / 25.97	— —	26.14	26.15	26.15	26.15	26.15		
0 + 08	26.00 / 25.[illegible]	— —	26.15	26.14	26.14	26.13	26.13		
0 + 10	— —	25.98 / 25.95	26.15	26.09	26.08	26.10	26.07		
0 + 12	— —	26.00 / 25.94	26.15	26.09	26.07	26.06	26.04		
0 + 14	— —	25.99 / 25.94	26.15	26.07	26.07	26.05	26.05		
0 + 16	— —	25.99 / 25.94	26.15	26.05	26.05	26.04	26.02		
0 + 18	— —	26.00 / 25.92	26.16	26.03	26.00	26.01	26.00		
0 + 20	— —	26.01 / 25.92	26.18	26.05	26.03	26.02	26.00		
0 + 22	— —	26.01 / 25.93	26.19	26.09	26.07	26.05	26.04		
0 + 24	— —	26.02 / 25.98	26.19	26.11	26.11	26.08	26.06		
0 + 26	— —	26.03 / 25.96	26.18	26.12	26.11	26.09	26.07		
0 + 28	— —	26.04 / 25.97	26.20	26.14	26.13	26.11	26.09		
0 + 30	— —	26.06 / 25.99	26.21	26.16	26.15	26.13	26.12		
0 + 32	— —	26.07 / 26.00	26.23	26.18	26.1[illegible]	26.15	26.14		
0 + 34	— —	26.10 / 26.02	26.25	26.20	26.19	26.17	26.16		
0 + 36	— —	26.11 / 26.05	26.26	26.21	26.20	26.19	26.18		
0 + 38	— —	26.14 / 26.02	26.28	26.23	26.21	26.19	26.19		
0 + 40	— —	26.14 / [illegible]	26.31	26.23	26.21	26.1[illegible]	26.19		
0 + 42	— —	26.17 / 26.05	26.32	26.22	26.22	26.21	26.21		
0 + 44	— —	26.19 / 26.0[illegible]	26.33	26.24	26.23	26.22	26.21		
0 + 46	— —	26.20 / 26.05	26.35	26.29	[illegible]	26.26	26.25		
0 + 48	— —	26.22 / 26.13	26.38	26.30	26.3[illegible]	26.28	26.28		
0 + 50	— —	26.26 / 26.19	26.4[illegible]	26.34	26.34	26.33	—		
0 + 52	— —	26.26 / 26.1[illegible]	26.42	26.37	26.3[illegible]	26.35	—		
0 + 54	— —	26.28 / 26.18	26.44	26.38	26.37	26.36	—		
0 + 56	— —	26.30 / 26.21	26.46	26.40	26.39	26.37	—		
0 + 58	— —	26.31 / 26.23	26.47	26.42	26.41	26.39	—		
0 + 60	— —	26.35 / 26.2[illegible]	26.50	26.46	26.45	26.43	—		
0 + 62	— —	26.39 / 26.31	26.54	26.49	26.47	26.45	—		
0 + 64	— —	26.42 / 26.31	26.59*	26.47	26.46	26.45	—		
0 + 66	— —	26.44 / 26.33	26.60*	—	—	—	—		
0 + 68	— —	26.49 / 26.40	26.55*	—	—	—	—		
0 + 70	— —	26.49 / 26.47	26.59*	—	—	—	—		

* Possibly invalid due to heavy equipment setting on AM-2 at time of shots.

Figure 41. Test 1-2, Centerline Profile Data, F-4 Load Cart Testing

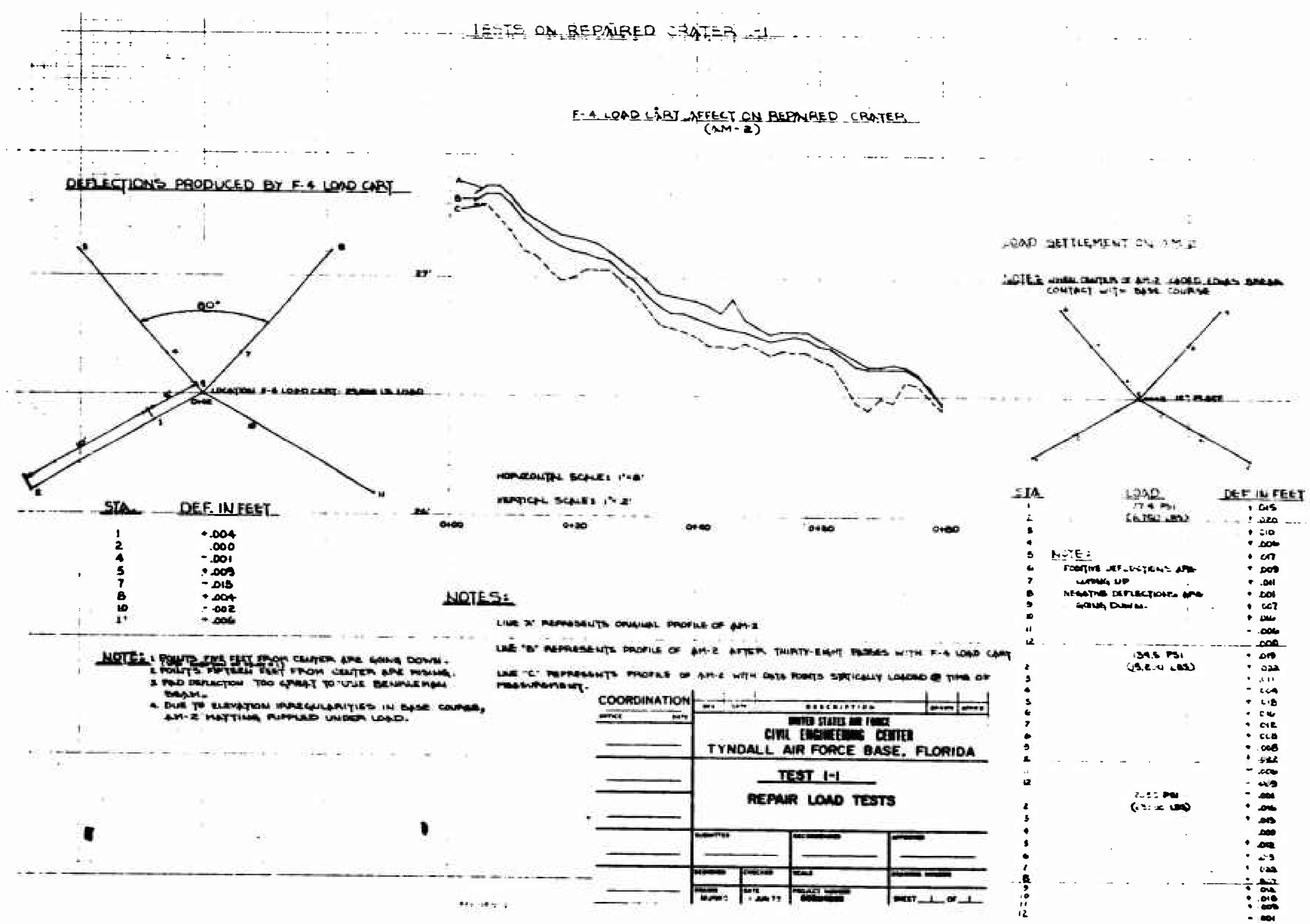


Figure 42. Test 1-2, Centerline Profile Before and After F-4 Load Cart Trafficking

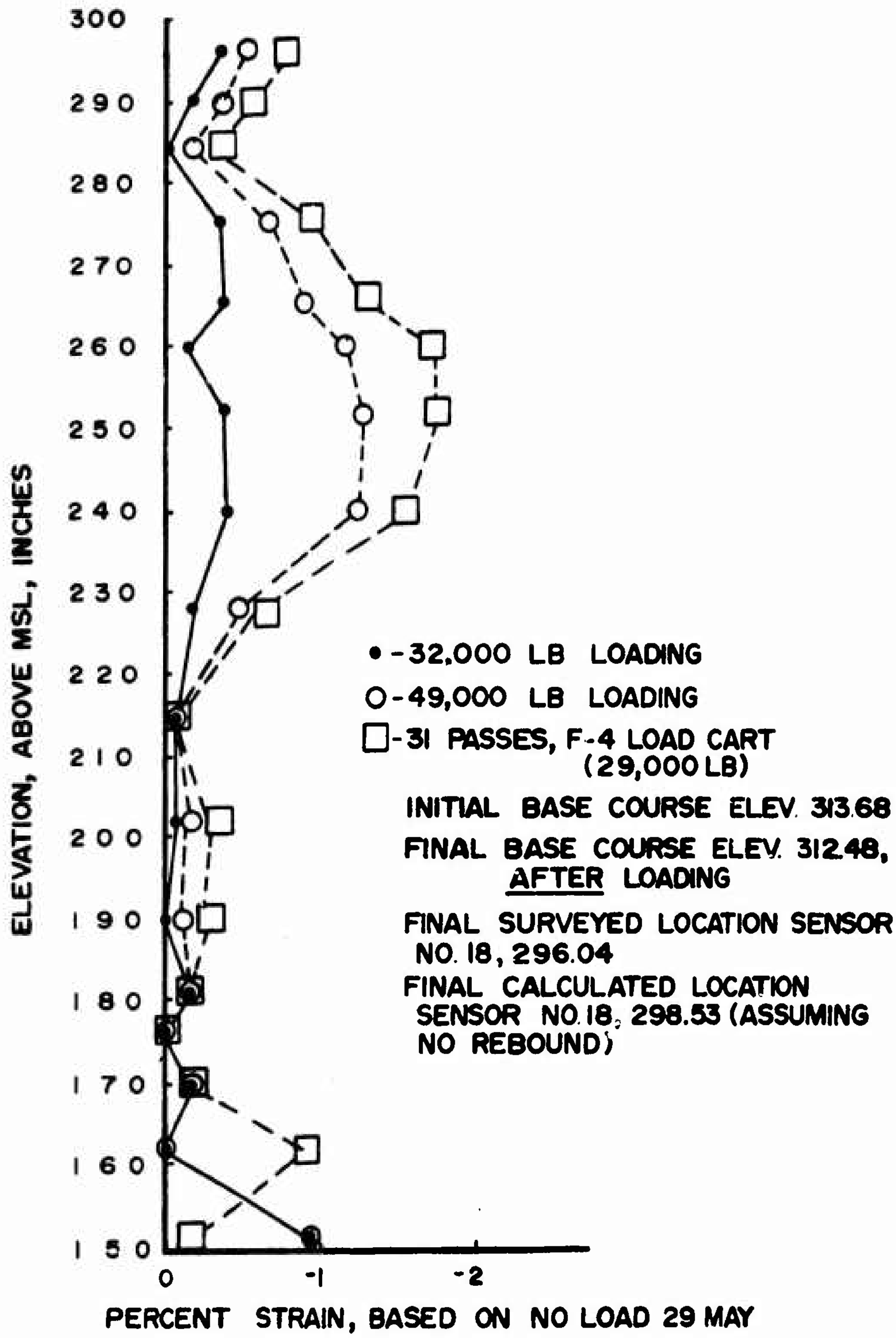


Figure 43, Test 1-2, Loading Strains

load and subsequent load cart testing consisting of 31 passes of the F-4C load cart along a single track. The cart was loaded to 29,000 pounds, representing the single main gear gross weight of an F-4C. Resulting strains shown in table 9 indicate little rebound upon the removal of the 49,990 pounds. Only one location showed rebound, located between sensor pair 1-2. Because of the rapid variation in strains indicated by sensor pairs 1-2 and 2-3, these pairs are thought to have given erroneous readouts. The presence of metal bomb fragments deep in the crater floor where these sensors were located, provides a possible explanation for erratic behavior. Erratic behavior of these sensors could also explain some of the difference between the final surveyed location and final calculated location of sensor No. 18. This error of some 2.49 inches or 0.21 foot, could also be explained by settlement of the crater bottom or sensor 1. Calculated position is based upon the calculated position of sensor 18 at the time of final compaction of the base course on 25 May. This calculation was based upon the known location os sensor 18 and the Bison gage measurements of the separations of all sensor pairs. It was not practical to excavate to determine the exact location of sensor 1 following the load testing. The information gained from Test 1-2 is not compromised by this discrepancy.

e. Analysis of Strain Information

(1) Load Distribution.

The most valuable information gained from Test 1-2 is shown in figure 43. The distribution of the load through the base course and backfill reached a point where rapid consolidation due to short term loading no longer constituted a BDR problem. In particular, it is seen that the influence of loading is minimal below a depth of about 7 feet. If a homogeneous condition could be assumed to exist following the saturation induced consolidation, the conclusion is that maximum consolidation for this 93-2 type repair occurs between 2.5 and 5 feet beneath the surface of the base course material. This leads to the conclusion that one can ignore extensive time consuming compaction on material deeper than 5 to 6 feet below the surface. Maximum compactive effort should be given to material less than 6 feet deep.

(2) Disturbed Crater Boundaries.

The questionable location of sensor 1 indicated that the bottom of the crater could create large surface deflection problems even if the crater were backfilled with a material of known and excellent engineering properties. In Test 1-2, the fallback material and the true crater floor were both excavated. Still, based on the location discrepancies of sensor 18, it can be assumed that sensor 1 moved downward. This occurred during the long-term settlement. It indicates that without excavating large amounts of fallback and sheared and crushed crater floor material, similar to that shown being tested (figure 44), excessive long-term settlements will occur regardless of how well the crater itself is backfilled. This leads to the conclusion that long-term settlements cannot be eliminated and that the repair technique adopted must be able to cope with them. This automatically eliminates a rigid crater repair surfacing. The British have already faced this problem, since a key portion of their repair techniques involves excavation of unsuitable materials from the crater (ref. 23).

(3) Suitability of Repair for Aircraft Use Without AM-2 Patch.

The second observation is based on reference 26. The CBR rating of the compacted debris was 13. Figure 45 indicates that the debris subgrade was uncapable of being utilized to launch F-4C type aircraft. Had the debris been brought up to the surface level of the runway, figure 45 indicates that it could have been used for up to 9 coverages by F-111A type aircraft without benefit of a capping material. The base course, with a CBR of 31 would have been capable of sustaining 160 coverages of F-4C type aircraft or 1,800 coverages by F-111A type aircraft. Load cart testing of the base course without the AM-2 surfacing was not attempted. Reference 2 indicates that a lengthy method of repair not utilizing AM-2 or other surfacing is acceptable. The above indicates that under the proper conditions consideration can be given to deletion of the AM-2 matting if the timely completion of aircraft mission requirements is in question.

f. Dynamic Loading.

In addition to the static loading, dynamic loading of the test repair was accomplished by the Civil Engineering Research Facility (CERF). This yielded the soil modulus of the undisturbed pavement system, the debris backfill, compacted base course, and the repair system including the AM-2 matting. All data pertaining to this testing is contained in appendix XI.

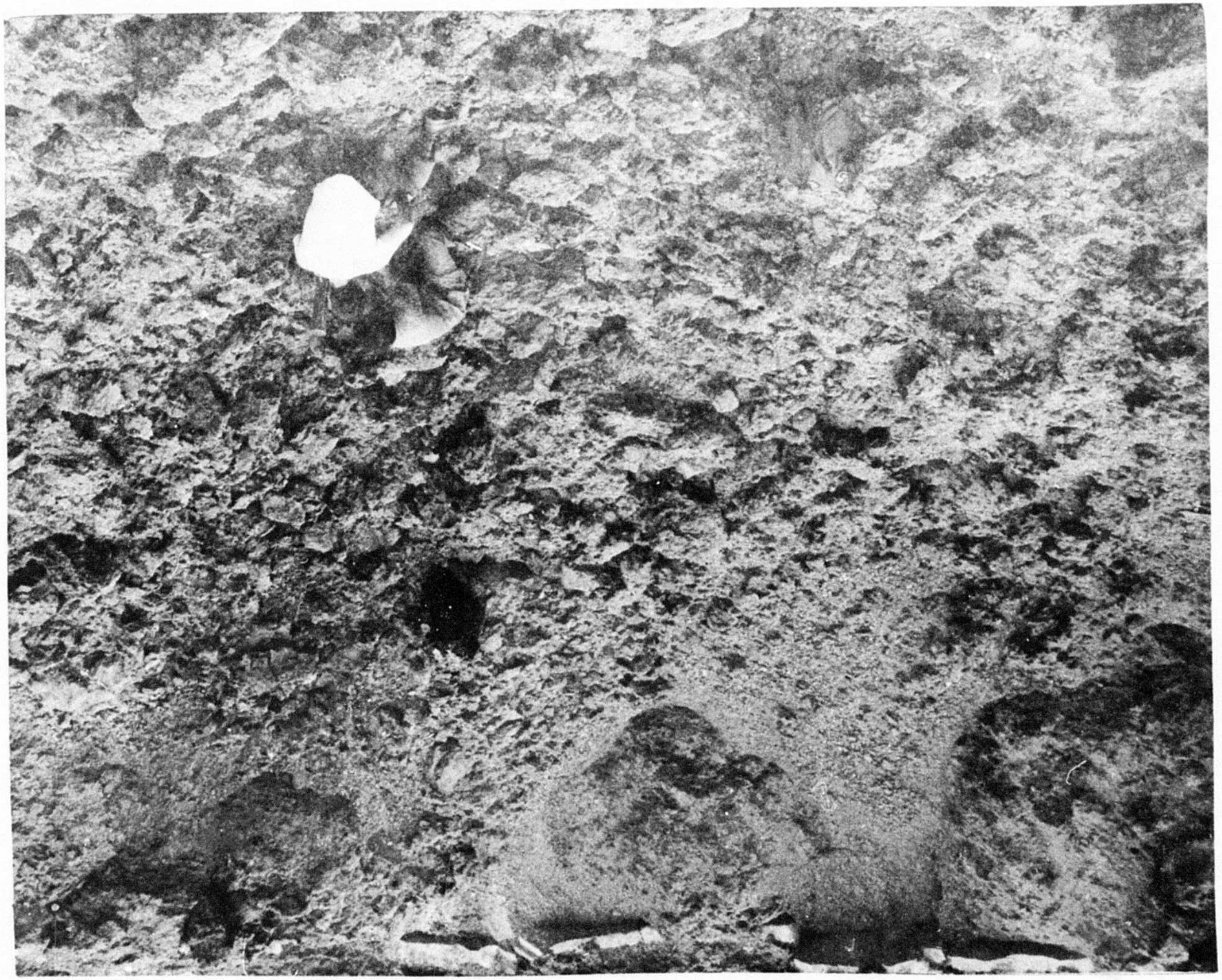


Figure 44. Test 1-2, Distorted and Sheared Crater Wall and Floor Material

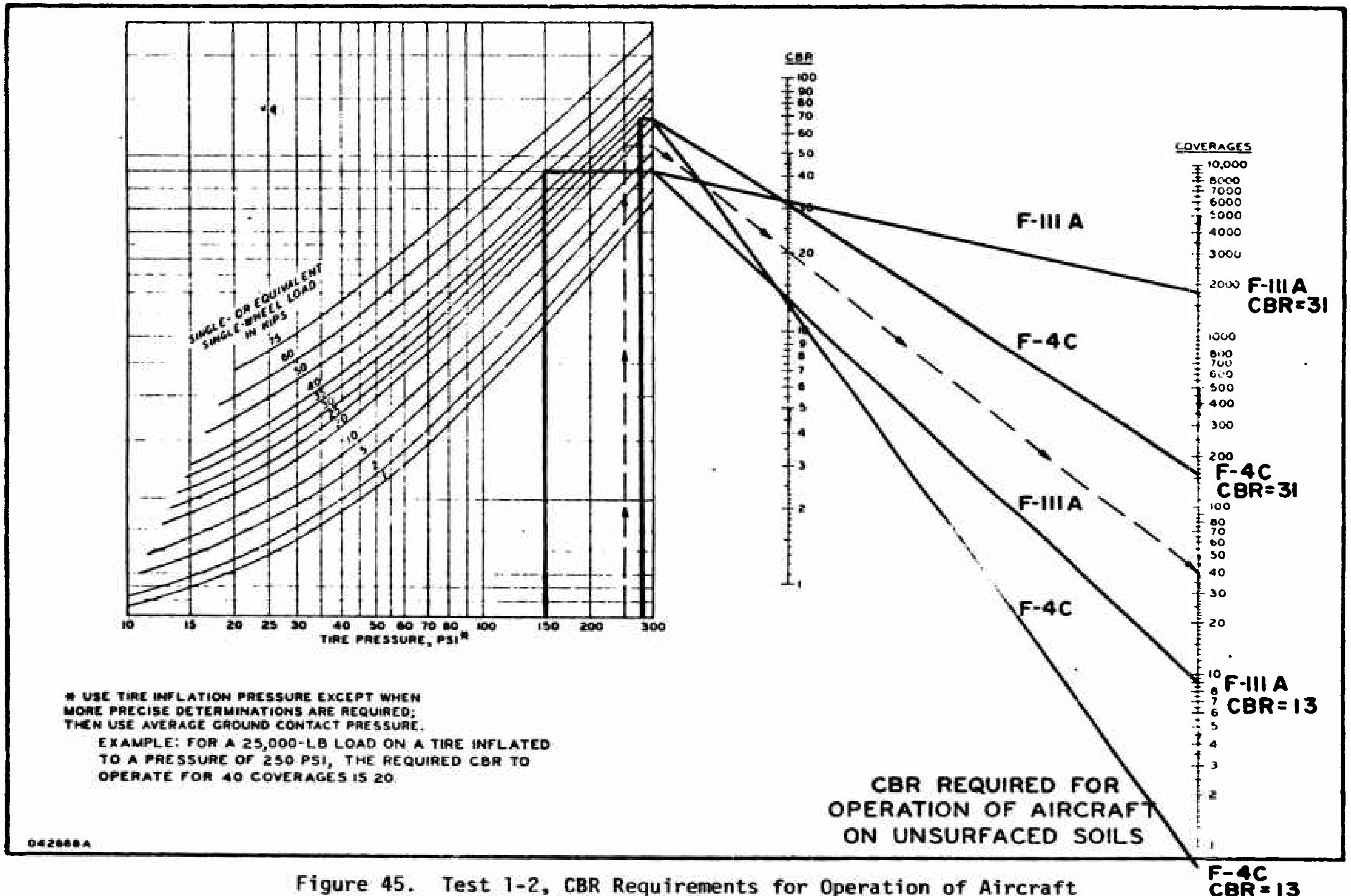


Figure 45. Test 1-2, CBR Requirements for Operation of Aircraft on Unsurfaced Repairs, after Reference 2.

3. EQUIPMENT TESTING.

Several items of equipment which are available at AFCEC but not necessarily in the base-level inventory were tested to determine their value in various phases of the BDR process. Although they did not represent all the types of equipment available in industry, they did represent most of the methods of operation of equipment that could be of use in BDR. Specifically, four types of equipment were utilized to attempt removal of debris and upheaved pavement without having to enter the crater, one item was used in an attempt to force the upheaved pavement back into place and one was used in the compaction of the select fill or base material.

a. Removal of Upheaved Pavement Outside the Crater.

During Test 1-1 it was noted that a primary cause of the excess repair time was the slow removal of heaved pavement. As was discussed earlier, it was noted that the equipment currently in the AFM 93-2 BDR package did not have enough power and/or weight to push the debris directly into the crater and therefore left a lip of debris at the crater edge which hindered progress and caused extra movements of equipment. Figures 46 A, B, and C display the upheaval following removal of fall back and ejecta. In figures 46A and 46C, stockpiled debris to be used in the backfill operation can be seen. Figure 46C shows the break point between the dramatically upheaved, but easily removed, pavement on the crater lip and the more subtly upheaved pavement that can extend 10 to 15 feet beyond the breakpoint.

Figure 46A. Test 1-2, Upheaved Pavement Cleared of Debris on the Left

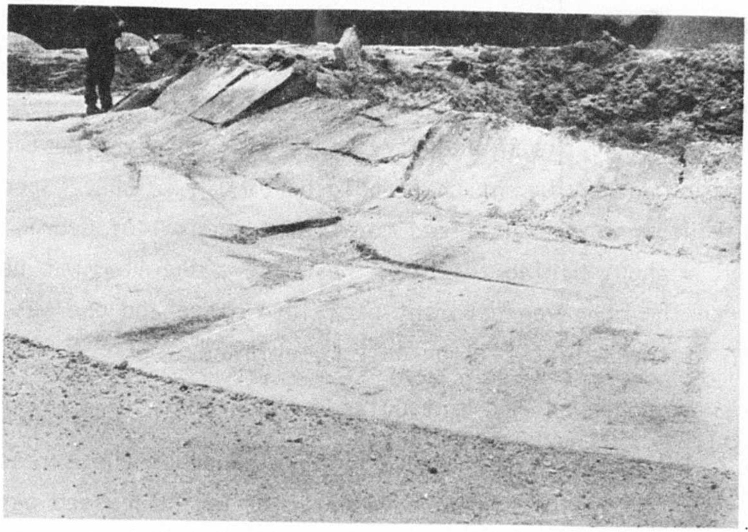


Figure 46B. Test 1-2, Close up of Upheaval

Figure 46C. Test 1-2, Close up of Two Distinct Breaks in Slope, Showing the More Difficult to Identify and Remove Upheaval to the Left

In several repair schemes, the equipment must be capable of working from the outside of the crater exclusively. This would be particularly important to bridging or structural fill methods of BDR, such as the PVC module method developed by Texas Tech University, where no equipment can be inside the crater. The tests run on four types of equipment are listed below.

(1) Allis Chalmer 745 Front Loader with four in one Bucket.

Data for this item is given in appendix X. Testing of this equipment was limited to activities on which no time and motion data are available. Observations on two of the features of this item were made, and photographic coverage and notes of the machines capability were made. The AC 745 is essentially an enlarged version of the AC 645 machines used in Test 1-1. Advantages for BDR include an increased capability to push ejecta and badly upheaved pavement directly into the crater. As shown in figures 47A, B, and C, the four in one bucket enables the machine to lift the badly upheaved pavement clear of the crater lip. In general, the added size and power are needed in the crater repair process, while the slight decrease in maneuverability of the machine is not significant enough to degrade the usefulness. Whenever a choice of equipment was allowed, the AC 745 was chosen by the equipment operators because of the added utility.

Figure 47A. Test 1-2, Operation of AC 745 Loader with Four in One Bucket in Closed Position

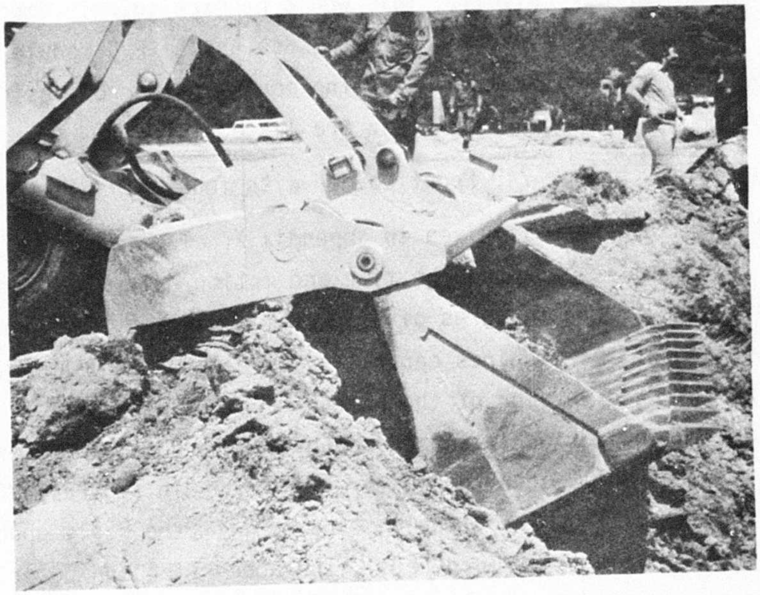


Figure 47B. Test 1-2, Operation of AC 745 Loader with Four in One Bucket Used to Lift Upheaved Soil on the Crater Lip

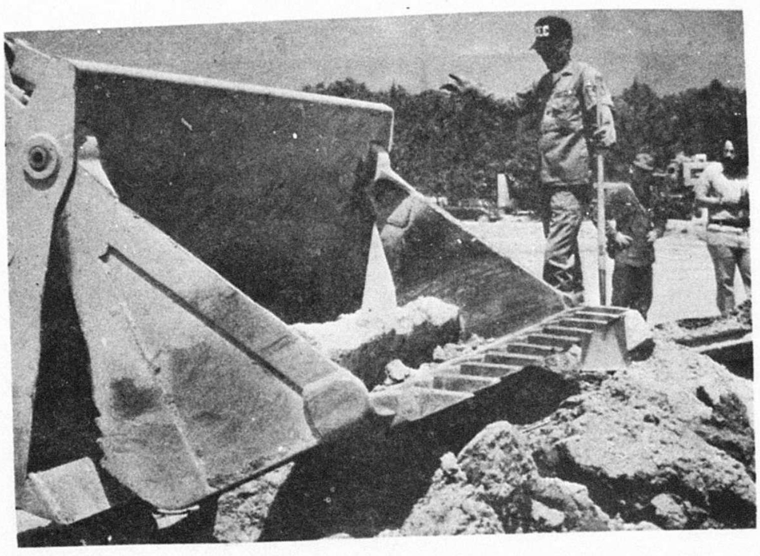


Figure 47C. Test 1-2, AC 745 Loader Lifting and Carrying Upheaved Pavement

(2) Other Equipment for Use Exterior to Crater.

Testing on three other types of equipment was performed by laying off 60 degree sections of the north end of the crater. All ejecta and badly upheaved pavement had been removed from the area by the AC 745 loaders and swept clear leaving only the less dramatically upheaved pavement which had created a problem in Test 1-1. Movies to allow time and motion studies were made of each piece of equipment; however, exact time comparisons between the equipment is not practical due to the extremely different performance characteristics of each. A brief analysis of the effectiveness of each follows:

(2) AC 645 Mounted Backhoe.

The unit in operation is shown in figure 48. The backhoe proved to be inadequate for this task and could only pull apart small pieces of concrete. It disturbed the base course below the runway, creating additional work for the repair crew (figure 49). While this size backhoe was inadequate, the British use large-wheeled backhoes in their BDR package (reference 23). Tests on this equipment were terminated due to its inadequate size.

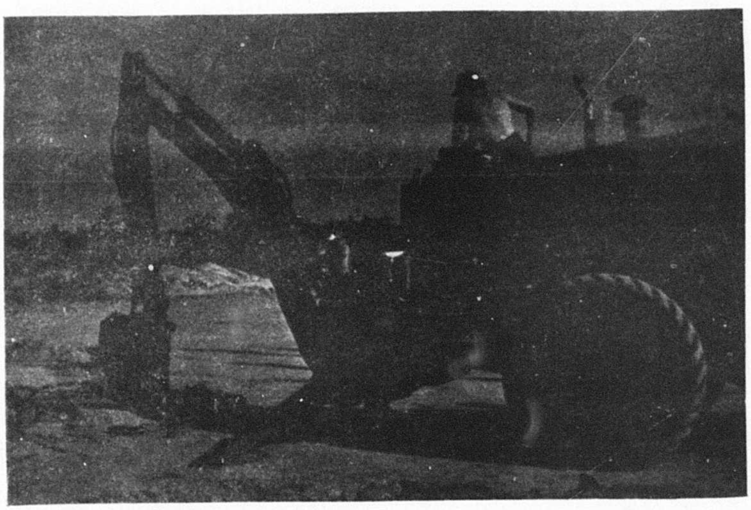


Figure 48. Test 1-2, Backhoe Attachment to AC 645 Loader in Operation

Figure 49. Test 1-2, Base Course Disturbed by AC 645 Backhoe Attachment

(b) 660 Gradall.

Data on this item are presented in appendix X. It is pictured in figure 50. While it proved to be a versatile piece of equipment, it lacked the size and power required to lift and break large concrete slabs. The operation and maneuverability proved to be adequate. The larger size Gradalls could be valuable in the BDR role, especially where a requirement exists to work from the outside of the crater. This equipment has many applications outside the BDR area, and from this viewpoint would be a valuable asset to the base civil engineer. Larger Gradalls used in highway and pipeline construction appear to be nearly as nimble as the 660 Gradall tested.

(c) Michigan 280 Rubber-Tired Dozer.

Data on this item are presented in appendix X. It is pictured in figure 51 working in Test 1-3. Tests with the 280 were extremely successful. The equipment was able to push all debris, including upheaved slabs, directly into the crater on one pass. In so doing, the circumferential crack furthest from the crater was easily located and further damage to the pavement was virtually eliminated.

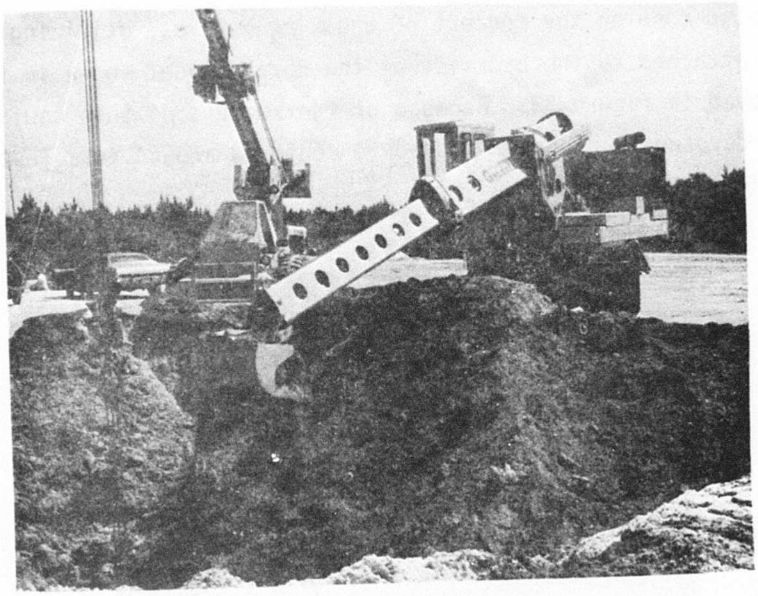


Figure 50. Test 1-2, 660 Gradall Removing Disturbed Soil from Inside the Crater

Figure 51. 280 RT as Used in Test 1-3, Pushing Debris Directly into Crater

Testing was also done on the concept of breaking concrete utilizing the ripper tooth attached to the backside of the dozer blade, shown in figure 52, and deployed in figure 53. Because of the success of this equipment, Test 1-3 was devoted to a repair procedure centered around it. Test 1-3 is covered in the next section.

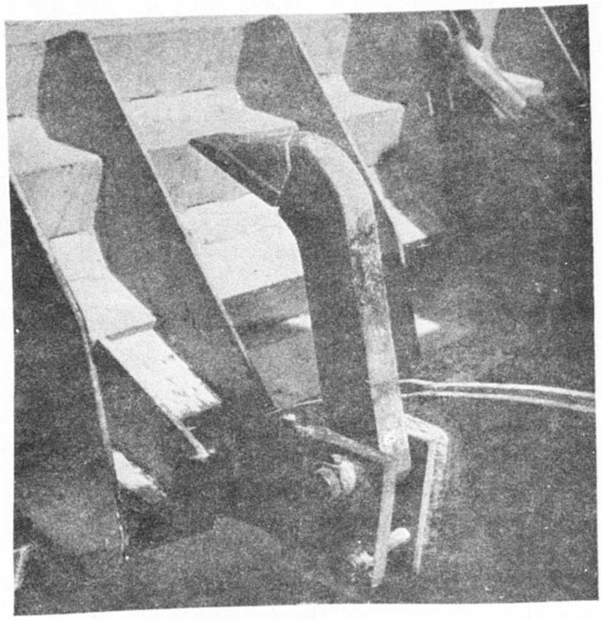


Figure 52. Test 1-2, Ripper Tooth Attached to Rear of 280 RT Dozer

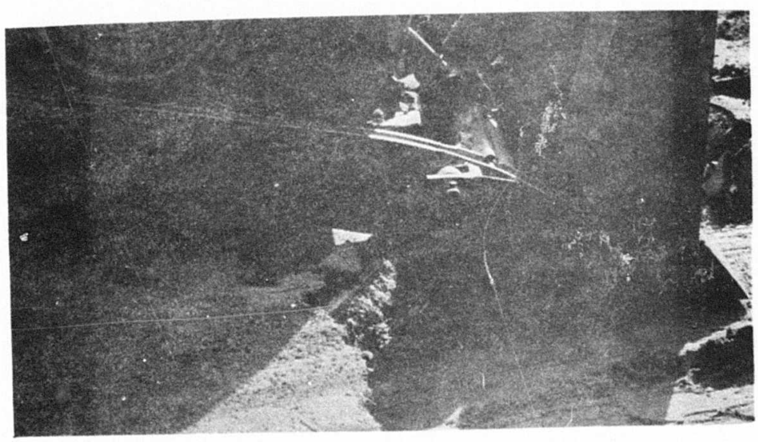


Figure 53. Test 1-2, Ripper Tooth Deployed and Lifting Upheaved Pavement

b. Recompaction of Upheaved Slabs.

The pieces of equipment used in this application was a bare base Tripactor, constructed solely for the bare base mission and stored and maintailed by the 823 CES, RED HORSE, Hulburt Field, Florida (figure 54). Members of the 823 CES who participated in Test 1-1 suggested during an out briefing that a large compactor, such as the Tripactor, might be able to recompact or force down a significant area of the upheaved pavement, thus reducing the amount of upheaved pavement which would have to be removed. Table 10 shows clearly that the Tripactor was ineffective. The most successful use was near the crater lip; however, to become serviceable, this area would require much more deflection than the 0.05 to 0.06 foot achieved. The dynamic forces which displaced the concrete by upheaval are too great to be undone by nonexplosive compaction.

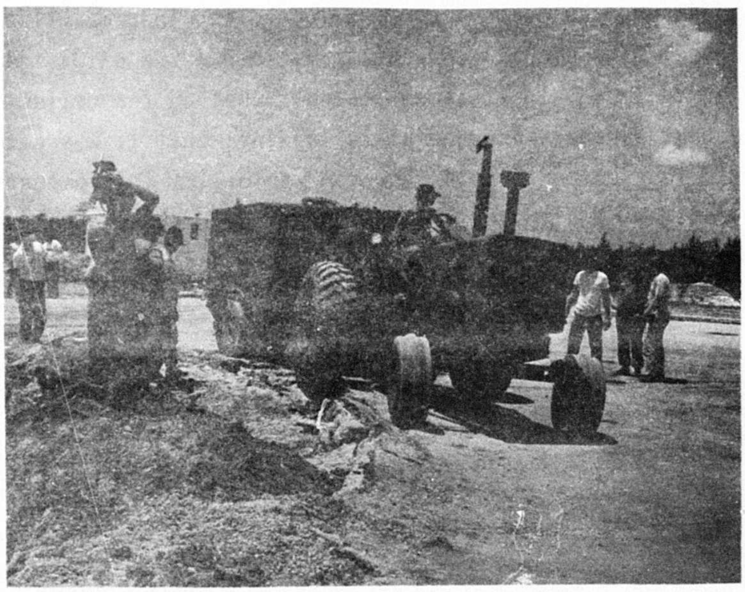


Figure 54. Test 1-2, Bare Base Tripactor Operating on Upheaved Pavement

Table 10

TEST 1-2, PERMANENT DEFLECTION OF UPHEAVED PAVEMENT FOLLOWING TEN TRIPACTOR PASSES

DISTANCE FROM CRATER LIP, FT	DEFLECTIONS, FT. LOCATION		
	1	2	3
1	-.06	-.13	-.05
3	-.04	-.05	-.05
5	-.05	-.05	-.04
7	-.03	-.03	-.04
9	-.04	-.04	-.03
11	-.03	-.03	-.04
13	-.03	-.03	-.03
15	-.02	-.01	-.03
17	-.02		

c. Base Course Compaction.

The final equipment test involved a rotary-drum vibrating compactor (figure 55). This was used to obtain maximum density of the select fill material. In addition, the other important ingredient in compaction, moisture, was liberally added. The overall compaction yielded a CBR of 31. Although a CBR was not taken in Test 1-1, it is estimated, based on the deflection of the AM-2 under load cart passages and the plate loading, that it was between 10 and 15. The excellent compaction is shown in table 11. This amounts to 112 percent of the optimum density and 104 percent of density as constructed. Both the compactor and a method of adding water are absolute requirements for successful use of the current BDR method.

Figure 55. Test 1-2, Vibratory Drum Compactor Used for Base Course Compaction

Table 11

TEST 1-2 REPAIR DENSITIES AND MOISTURES

		DENSITY, PCF	MOISTURE CONTENT, %	CBR
Compacted Debris Top of Subgrade	pt.	98.4	4.5	13
Compacted Base Course, Top	1	152.3	5.4	31
	2	152.5	5.3	
	Average	152.4	5.4	

4. AM-2 AIRFIELD PATCH ATTACHMENT

a. A further portion of Test 1-2 was the testing of a new method of attaching the AM-2 matting to the surface. Two items had been shown to be inadequate in the system proposed by AFM 93-2. First, the rotary electric drills specified in AFM 93-2 were inadequate to drill the required number of holes. Test 1-1 was in fact terminated before the drilling procedure was completed. Second, the expansion shields placed in the drilled holes were not capable of withstanding either shearing or tension in asphalt. These would not only fail to restrain the matting, but, once loose could inflict damage to aircraft engines.

b. The problem of drilling holes was remedied by using an impact electric rotary hammer. The particular model was a Black and Decker Model 723 Super Rotary Hammer, Type C-8. This hammer was capable of drilling the required 54 holes to a depth of 3 inches in a total of 12 minutes. While one hammer is sufficient, it is recommended that a backup hammer be included in the kit, or a total of 6 per base.

c. The problem of seating the bolts in the hole is more difficult. Several types of expansion bolts were tried, however, a new type of hardware will have to be sought out or designed for this application, and must be matched to the bit used in the rotary hammer. A suitable interim system was devised using bolts anchored head down in a lead-sulphur compound (figures 56A, B, and C). This worked well with the entire job using this method requring only 19 minutes. An attempt was made to remove the bolts the following day with a grader blade. The bolts bent, but could not be removed (figure 57). However, the electrical equipment required to heat the lead-sulphur must be started in advance. In addition, use of the electrical

melting pots and the laddling of hot lead-sulphur is somewhat cumbersome. Some method of removing the excess bolt head extension must be developed to insure no damage to aircraft tires is possible.

d. The development of a suitable expansion bolt for use in asphalt and concrete should be pursued to eliminate added items of equipment required for the lead-sulphur method. Further work on defining the shear and tension forces which the anchoring system must resist should be done before this development is undertaken.

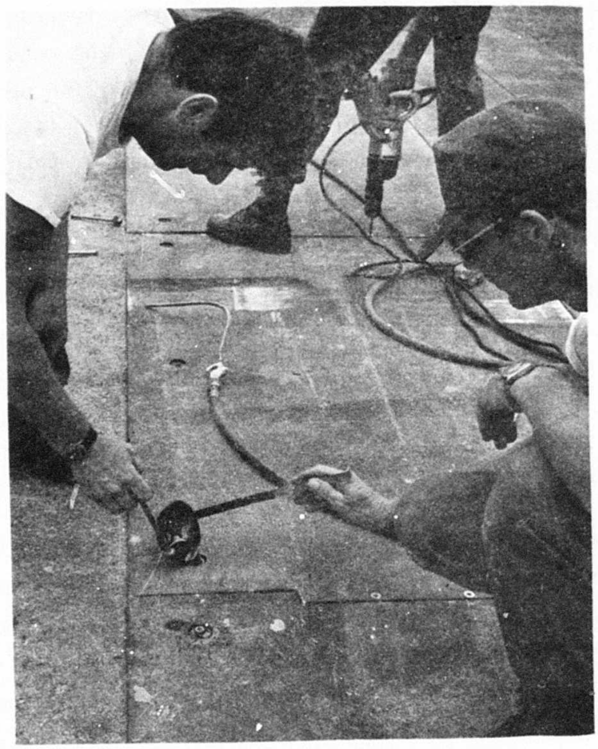


Figure 56A. Test 1-2, Molten Lead-Sulphur Ramp Attachment Method of Pouring Lead-Sulphur Compound into Drilled Hole. Bolts and Device Used to Clean Hole are Visible in the Background

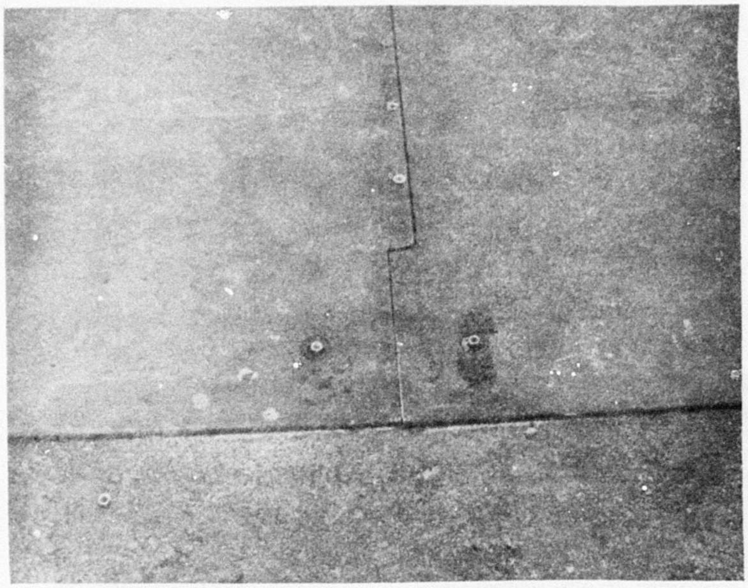


Figure 56B. Test 1-2, Molten Lead-Sulphur Ramp Attachment Method with Anchor Bolt in Place

Figure 56C. Test 1-2, Molten Lead-Sulphur Ramp Attachment Method With Close up of Bolt in Place, Showing Requirement for Grinding

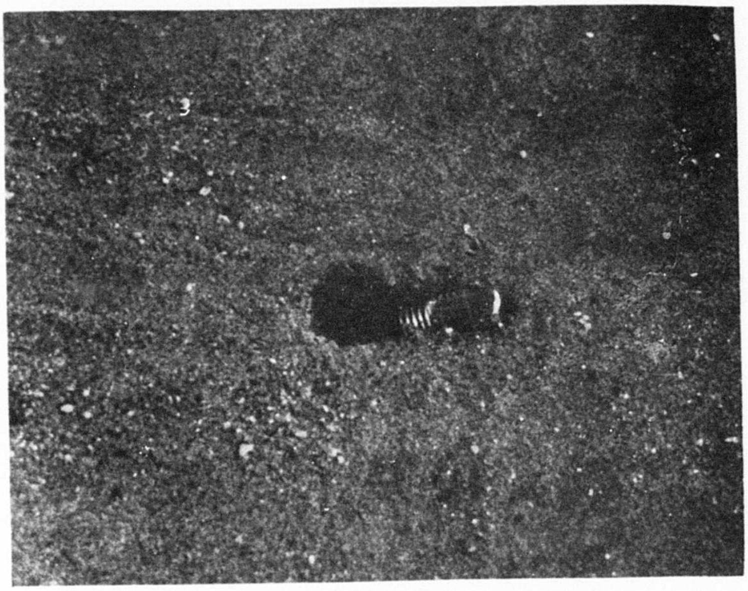


Figure 57. Anchor Bolt after Attempts to Remove with Motorized Grader

SECTION V

TEST 1-3

1. OBJECTIVES

a. Primary Objective

The main objective was to determine if the Michigan 280 Rubber-Tired Dozer, a 400-HP machine, could be effectively used to reduce the total repair time. The use of larger equipment such as this was generally discouraged in earlier BDR studies in favor of smaller more maneuverable and versatile equipment. This was primarily due to a requirement that equipment be capable of transport by C-130 aircraft, making the equipment compatible with the Bare Base concept.

b. Other Objectives

(1) Backfill Material

It was important to determine if the material in the near vicinity of the crater was of sufficient quality and quantity to satisfy the backfill requirements for the crater. This includes the material within the 54-foot wide area required to be cleared for the AM-2 repair patch.

(2) Compaction

It was advantageous to determine if compaction obtained by working rubber-tired equipment on the subgrade only at the completion of the debris backfill process would be adequate for an expedient repair. This would allow all backfilling to be done from outside the crater and would reduce the repair time involved in backfilling. This backfill would be extremely nonhomogeneous, containing large amounts of concrete debris. Much of this debris would be near the subgrade select fill interface.

(3) Cratering Information

Information on the response of runways to buried weapons was desired. In particular, the sand subgrade provides a condition differing from the clay subgrades in Tests 1-1 and 1-2. Information derived from this test is included in section IX on cratering. Figure 58 shows the crater prior to repair (compare to figure 8, Test 1-1).

Figure 58. Test 1-3, Crater Prior to Repair

2. CONDUCT OF TEST 1-3

Test 1-3 was conducted with the use of four pieces of equipment, including the Michigan 280 rubber-tired dozer, the WABCO 400 Motorized Grader, an industrial tractor towing a rotary broom and, finally, an International TD20 full-tracked dozer. The last piece of equipment was to be used only if required. The basis of repair procedure was the initial encirclement of the crater by the 280 RT, pushing in all ejecta. The 400 grader was meanwhile utilized to clean the area of smaller debris and to clean behind the 280 RT such that it could be determined if more upheaval must be pushed into the crater. The encirclement by the 280 is shown in figure 59. The area to be cleared is shown in figure 60. Repair was to be terminated with the final clean up by the towed rotary sweeper. No base course material (select fill) or capping was to be used in this test, since their placement was not required to meet the objectives of the test.

Following completion of the repair, soils tests were made to determine the CBR of the subgrade as placed. In addition, profiles of the repair were made to ensure conformance of the final repair to the criteria established for vertical pavement displacement.

Figure 59. Test 1-3, 280 RT Completing Initial Encirclement of Crater

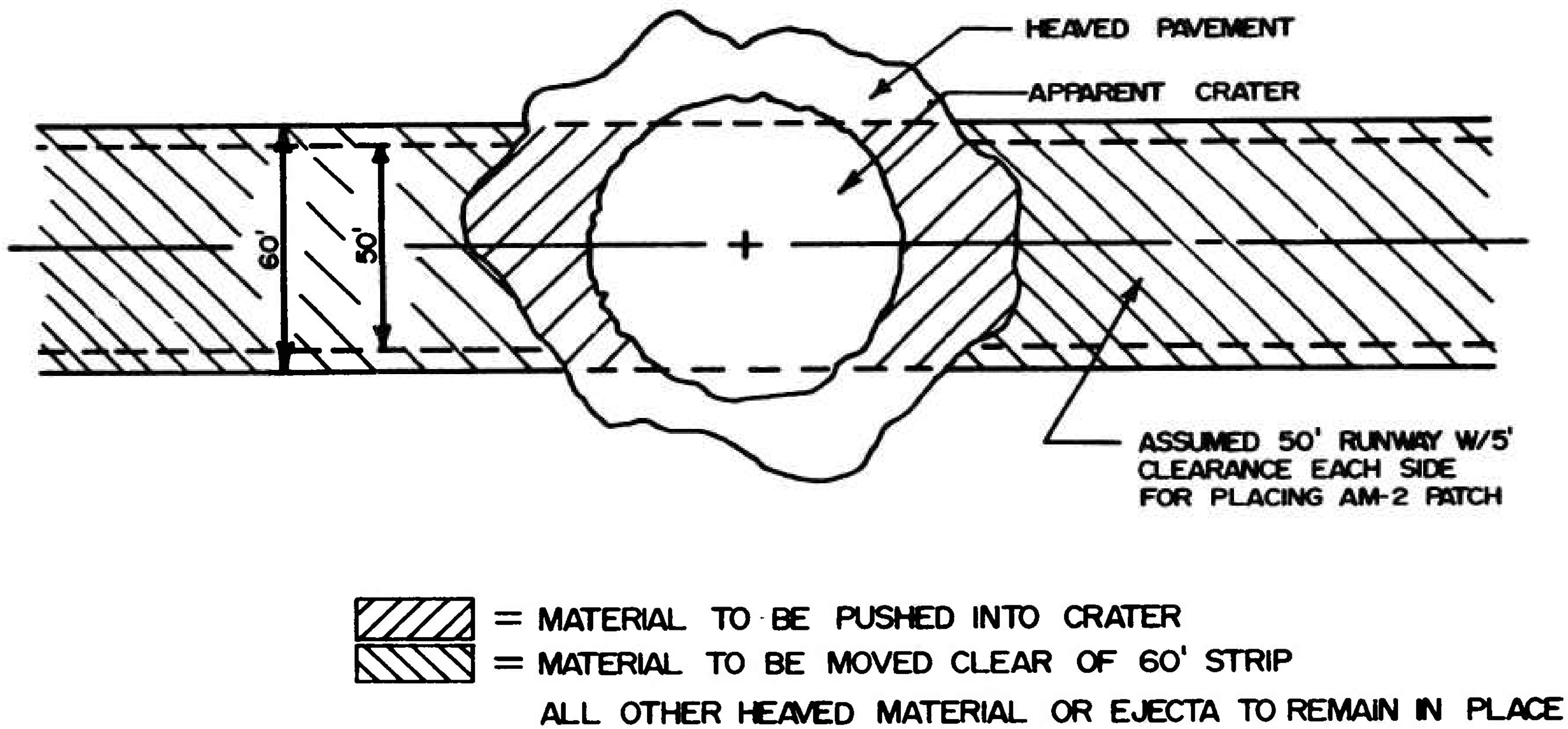


Figure 60. Test 1-3, Areas to be Cleaned and Material to be Moved, Debris Backfill Procedure

3. PROCEDURE AND EQUIPMENT EVALUATION

a. PROCEDURE

Because of the problem encountered with the use of the 280 RT noted below, the procedure took longer than had been expected. One factor causing excessive time was the over filling of the crater (figure 61) with debris and the tardy switch from working outside the crater to working inside. It was originally felt that the 380 RT could handle the entire job from outside the crater. In addition, if a machine capable of uplifting the pavement had been moved inside at an earlier time, (figure 62) the elapsed time would have been further reduced. In general, the procedure worked well as witnesses by table 12, a schedule of events during the actual test. Had the crater not been overfilled with debris the use of the TD 20 tractor would have been avoided. This equipment package and procedure was far superior to that exercised in Test 1-1, and is the basis of the proposed repair procedure and equipment package suggested later.

Figure 61. Test 1-3, Overfilling of Crater with Debris

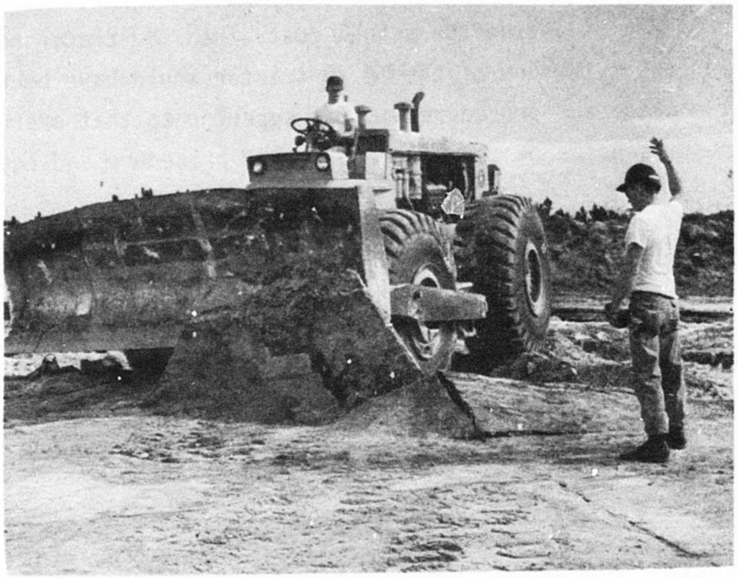


Figure 62. Test 1-3, 280 RT Lifting Upheaved Pavement from Inside the Repair

Table 12

TEST 1-3, ACTIVITIES LOG

280	Michigan 280 Rubber Tired Dozer
400	Wabco Motorized Grader, Model 400
TD20	International Harvester Full Track SZ 4 with Dozer Blade

28 August 1973

1255	Start Test, 280 and 400 work clockwise around crater.
1305	280 Down with Hydraulic leak, test postponed.

30 August 1973

0800	Restart Test, 280 and 400 work clockwise around crater.
0810	280 has completed 360 degrees with large upheaval, is beginning to push less dramatic upheaved slab into crater.
0822	400 completed cleanup of small debris, cleaning behind 280.
0830	400 continues to help 280.
0855	Removal of upheaval 60 percent complete, 18" - 24" excess noted in crater, 400 idle.
0905	Excess removed, breaking of upheaval started again.
0922	TD20 helping to clear excess being pushed out by 280; all upheaval gone.
0927	280 backblading in crater.
0940	Rotary sweeper beginning to sweep.
0945	TD20 and 280 completed.
1010	Rotary sweeper completed project.

b. Equipment

(1) Michigan 280 Rubber Tired Dozer (280 RT)

This equipment was handicapped in this application due to two factors. First, the ripper teeth were not deployed and as a consequence a portion of the excellent potential noted in Tests 1-2 and 1-4 was not utilized. Second, the machine was utilized outside the crater for about 30 minutes after it was first realized that the 280 RT would not be able to shove the more moderately upheaved slabs directly into the crater without first breaking them free by some form of vertical force. The time consumed in attempting to remove excess material from the interior of the backfilled crater was not an equipment problem, but rather a procedural and test supervision problem. It was originally thought that it would be a simple matter to remove excess material from the crater. This was not so. The 280 RT could serve the role of compacting the debris well due to the high gross weight, and is seen in the compaction role in figure 63. In general, the 280 RT was satisfactory in performance, however, it does require a carefully planned and supervised repair procedure and the proper support equipment package to be effective.

Figure 63. Test 1-3, 280 RT Being Used for Final Compaction of the Debris Subgrade Surface

(2) WABCO 400 Motorized Grade

This equipment displayed the same capabilities seen in Test 1-1. No repair procedure would be effective without it. It is not a good piece of equipment for working close to the crater, however, it was effective in cleaning smaller pieces of debris behind the 280 RT. Although no base course material was placed in this test, it should be realized that the motorized grader is an absolute necessity for that operation, particularly in the final grading process. In some applications, such as cleaning large portions of the runway covered with small debris, a 14-foot blade would be advantageous.

(3) Towed Rotary Broom

This equipment is a mandatory requirement for effectively cleaning the repair area. In addition, it is desirable to sweep the crater area before placing the AM-2 matting, both to ensure detection of all areas of upheaval requiring removal, should any have been missed due to light debris coverage, and to ensure no material under the outside edges of the matting can become available for ingestion into aircraft engines.

(4) International Harvester TD20 Full Tracked Dozer

The use of this equipment was not an absolute necessity, but resulted from an error in allowing the crater to be filled in excess of requirements.

c. Time Results

The time for this test, table 12, were considerably reduced from those in Test 1-1. A total of 2 hours and 20 minutes (2:20) were required from start until completion of the sweeping procedure. However, only 20 minutes time (10 minutes on 28 August and 10 minutes on 30 August) were required for the 280 RT to encircle the crater one complete time. An additional 45 minutes were required to remove 60 percent of the moderately upheaved material. A total time of 1 hour and 22 minutes was required to remove all upheaval. With the proper equipment mix to support the 280 RT, such as a fork lift within the crater or fork attachments on the 280 RT, the time for this portion of the repair could easily be reduced to as low as one hour. A total time of 2 hours and 51 minutes were utilized for this same operation in Test 1-1, or 86 percent more time than Test 1-3.

4. SOIL TESTS AND LOADING

Table 13 shows the densities of the subgrade surface following the crater repair. Also shown are the CBRs obtained at both 0.10 foot and 0.20 foot penetration. Appendix V shows the location of CBR tests within the repair area. The low density and the CBRs obtained both indicate that more care must be taken with the compaction of the subgrade surface, although the poor compaction is due partly to the dry condition of the sand subgrade debris. No plate loading tests were taken. Since the CBR is a rating of the surface only, it is not known exactly how well the debris would have withstood loading. Information was also obtained on the boundary soil conditions of the crater, including soil density and moisture content in the apparent and true crater walls. This information is contained in section IX. A repair area of 2268 square feet resulted from the use of the equipment package defined above. The repair area is shown in appendix V. It is equivalent to a repair diameter of 53.7 feet.

Table 13

TEST 1-3, REPAIR DENSITIES AND MOISTURES

	No.	DENSITY PCF	MOISTURE PERCENT
Compacted Debris,	1	105.3	3.0
Top Subgrade	2	104.5*	2.8
	Average	104.9*	2.9

*Some concrete fragments included.

CBR's @ Top of Subgrade

Test	@.10 Penetration	@.20 Penetration
1	3.9	4.6
2	1.9	2.1
3	.8	1.7
4	2.8	4.0
Average	2.4	3.1

5. PROPOSED REPAIR PACKAGE

a. Description

Table 14 is a listing of the optimum equipment package determined from Tests 1-1, 1-2, 1-3 and 1-4. This package is limited to items actually in

Table 14

OPTIMUM EQUIPMENT PACKAGE, DEBRIS BACKFILL AND AM-2 CAP BDR PROCEDURE

Item	Abbreviation	Per Crater	X 3	Runway at Large	Total	Current Package TA 010	Change	Remarks
Truck, Pick-up, ½ Ton	PU	0	0	2	2	2	0	Essential for coordinating activity.
Tractor, Truck 10 Ton	TT	1	3	0	3	3	0	Utilized with three different semi-trailers.
Semi Trailer, Flat 20 Ton	STF	1	3	0	3	0	+3	Used for permanent storage of AM-2 BDR kits
Semi Trailer, Lowboy 20 Ton	STL	1	3	0	3	3	0	Only required for Full Tracked Dozers.
Semi Trailer, Tank 5000 Gal.	STT	1	3	0	3	0	+3	Required for compaction sand and select material.
Loader, Scoop Tired 3 Yd AC 745	LDR	1	3	1	4	0	+4	Required for Stockpile, pavement uplift, contingency.
Fork Lift Atch Loader	FK	1	3	0	3	0	+3	Required for Unloading AM-2, lifting upheaved pavement.
Tractor, Full Track, SZ 4 (TD20)	TD	1	3	0	3	3	0	Required only under certain conditions, 1 minimum.
Tractor, 400HP Rubber Tired (280 RT)	RTD	1	3	0	3	0	+3	Required in cleanup, backfill, select fill placement.
Grader, Motorized 12' Blade	GRD	1	3	0	3	3	0	Required for all cleanup, select fill grading.
Truck, Dump, 5 YD or	DPT	6	18	0	18	15	+3	6 required to haul 142 YD/HR/Crater
(Truck, Dump, 10 YD	DPT	3	9	0	9	0	+9	Would eliminate 15 from current package.)

Table 14

OPTIMUM EQUIPMENT PACKAGE, DEBRIS BACKFILL AND AM-2 CAP BDR PROCEDURE (Continued)

Item	Abbreviation	Pre Crater	X 3	Runway at Large	Total	Current Package TA 010	Change	Remarks
Tractor, Industrial Wheeled	TI	1	3	0	3	2	+1	Utilized with Rotary Broom and with Vibratory Compactor.
Vibratory Compactor	VRC	1	3	0	3	0	+3	Required for proper select fill compaction.
Sweeper, Rotary	SR	0	0	3	3	2	+1	Required for runway cleanup, AM-2 fab site cleanup, etc.
Sweeper, Vacuum	SV	0	0	2	2	2	0	Required for final runway cleanup (FOD).
Crane, Truck Mounted, 20 Ton		0	0	0	0	1	-1	Test 1-1 revealed no requirement.
Loader, Scoop Tired, 2.5 CY AC 645		0	0	0	0	7	-7	Replaced by 3 CY Loaders, 400HP Rubber Tired Dozers.

the Air Force inventory since only those were tested. It is possible that more ideally suited equipment is available off-the-shelf than that tested. In addition, it is felt that more suitable equipment could be designed and constructed, often by minor modifications to the existing equipment. The use of forks easily applied to the 4-in-1 bucket used on the 645 and 745 equipment available in the inventory is an example of the latter. It is emphasized that each base may require separate treatment. For example, a rubber-tired dozer cannot be used in the interior of the crater at a base which utilizes a wet clay as subgrade material. This is pointed out in section III, Test 1-1. In addition to the equipment listing in table 14, figure 64 delineates the sequence of events and uses of equipment for suggested repair procedure. A narrative of the content of each of the ten activities comprising the procedure and nonself-explanatory equipment usage is presented below.

(1) Mobilization (30 minutes)

As demonstrated in Test 1-1, mobilization requires time even when the BDR team is knowledgeable of the required repair and is assembled at a marshalling point. To reduce the mobilization time required, three flatbed trailers are included in the package in addition to the three lowboy trailers included in the current package. The purpose is to have the AM-2 kits stored on trailers ready for deployment. This allows the lowboy trailers to be used exclusively to haul the tracked dozers to the site if required rather than forcing the tracked dozers to walk in. Mobilization would also include delineation of the repair area by the team chiefs and crater chiefs, layout of the patch assembly area and establishment of required communications.

(2) Crater Backfill (1 hour)

This process would include the first encirclement of the crater by the rubber tired dozer or the track mounted dozer. The track mounted dozer would only be required when the subgrade conditions were such that rubber tired equipment could not be used in the crater. In addition, the other heavy equipment specifically required for later tasks would be used as needed. The use of tank trailers in this activity would be only in the case of a granular subgrade where water would materially aid compaction or when the select filled is stored in a dry condition. The backfill process would stop with the encirclement of the crater from outside, since it was observed in Test 1-3 that the crater was amply backfilled following the placement of the nearby debris and dramatically upheaved pavement on the crater lip.

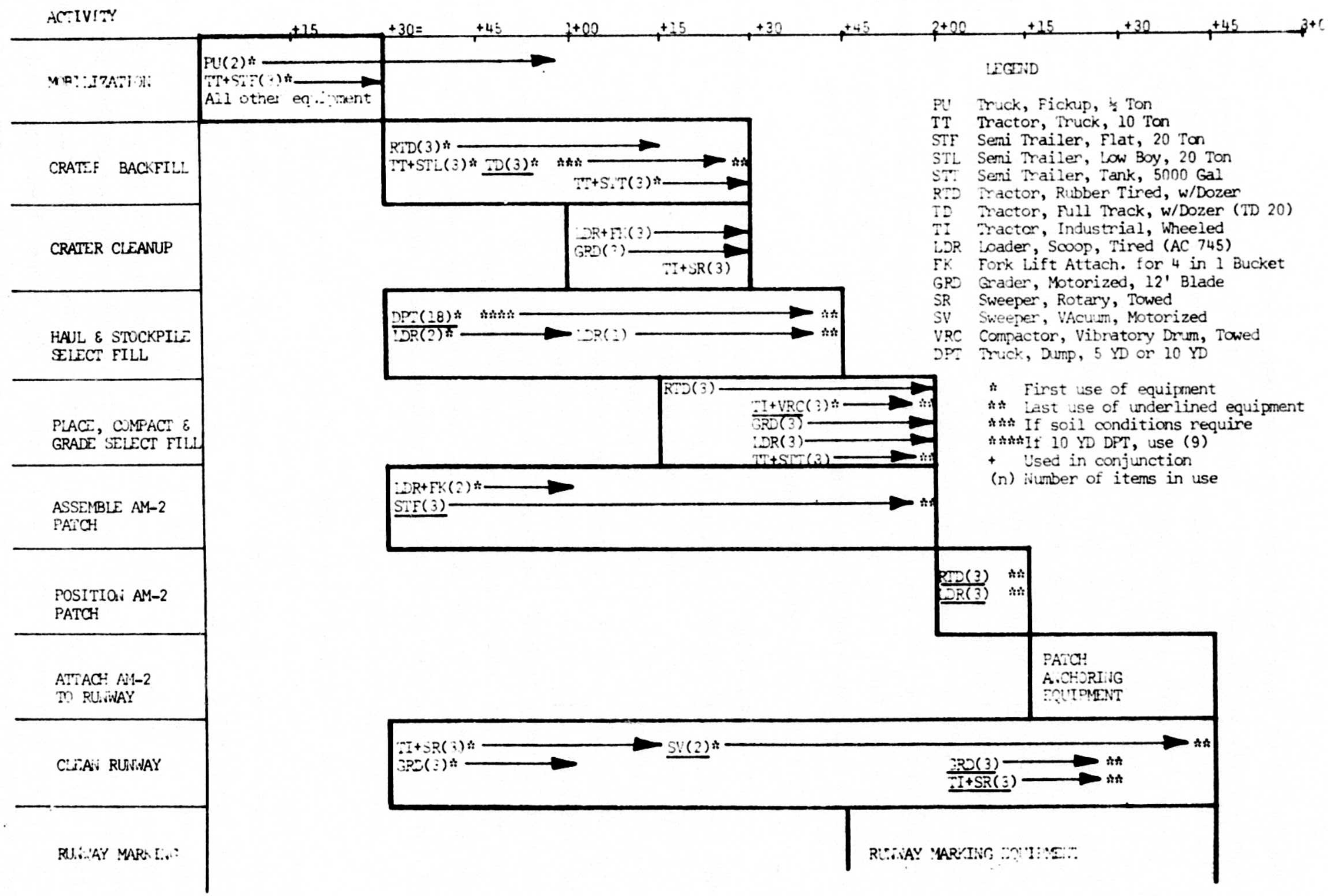


Figure 64. Proposed Repair Package, Sequence of Events and Equipment Usage

However, if the subgrade was not within a foot of the pavement surface, further debris would be pushed in to avoid hauling extra select fill.

(3) Crater Cleanup (30 minutes)

The crater cleanup would begin as early in the backfill process as possible, and would consist of the loaders equipped with fork attachments entering the crater to lift and push out of the repair area pavement identified as upheaved beyond tolerance, but located farther from the crater than the dramatically upheaved pavement along the crater lip. This pavement is seen in figure 46, section IV and in the profiles presented in appendix V. To identify this upheaval will require cleaning of the crater perimeter by the motorized grader and the towed rotary brooms, working on the areas cleared by the rubber tired dozer. During this time, the rubber-tired or tracked dozer, as applicable, would operate in the crater, leveling and compacting the backfill subgrade.

(4) Haul and Stockpile (1 hour and 15 minutes)

While the backfilling and cleaning is in process, the select material will be hauled from the stockpile areas and placed next to the crater where it can be drifted into the crater by the rubber-tired dozer when needed. It is seen that two 745 loaders are originally assigned to the stockpile to meet the initial surge of trucks. The other two 745's are assigned to unload AM-2 mat kits. Following this initial surge, one loader is assigned to the stockpile. Based on the haul times determined in Test 1-1 of approximately 15 minutes per round trip, a total of six 5-yard dump trucks loaded with six yards of materials each will be required to complete the hauling of the 142 yards of material required for each crater in 1 hour and 15 minutes. This time allows 15 minutes for the initial loading delays. The same job could be done with three 10 yard trucks per crater if they were loaded with 12 yards of material. An important advantage of the larger trucks is the resultant lessening of congestion by having a total of nine large trucks hauling instead of 18 smaller trucks. This also results in the use of nine less operators.

(5) Place, Compact, Grade Select Fill (45 minutes)

This activity can be started as soon as it will not interfere with the cleanup operation. The use of water tank trucks and the vibratory roller

is essential to insure an adequate subgrade when a flexible repair surface such as AM-2 is utilized. The method of placing and compacting the select fill was verified in Test 1-2.

(6) Assemble AM-2 Patch (1 hour and 30 minutes)

Areas for patch fabrication would be identified by the crater supervisor, and the first order of business in activity 9 (clean runway) would be the cleaning of the fabrication site. While cleaning is in progress, the BDR AM-2 kits would be off loaded by two loaders with fork attachments.

(7) Position AM-2 (15 minutes)

Upon completion of the grading and compacting of the select material and the fabrication of the AM-2 patch, the mat can be positioned with rubber-tired tractors and the loaders. It was demonstrated in Test 1-2 that the rubber-tired tractor could easily handle a patch without the aid of other equipment. However, less stress is created in the matting when two pieces of equipment are utilized. In addition, twisting or turning of the mat to the correct position is facilitated by the use of two pieces of equipment.

(8) Attach AM-2 to Runway (30 minutes)

It was demonstrated during Test 1-2 that with the proper tools and methods (see section IV), it is possible to anchor the patch to the runway in 30 minutes.

(9) Clean Runway (2 hours and 15 minutes)

The time allotted for this activity is somewhat misleading. As seen in figure 64, several items of equipment are withdrawn from the runway cleaning for use at the crater when required. Because of the limited test section size at the Tyndall BDR test site, no reliable data on the use of cleanup equipment were generated. However, the time allotted in this procedure is ample. Any trimming of the time would not be of value, since the item would not be on a critical path of activities. The heavy rubber-tired equipment can be utilized in the task to begin clearing heavy debris outside of the required 50-feet x 5000-feet temporary runway area.

(10) Runway Marking (1 hour)

No testing of this activity was done at Tyndall. For many parts of the runway, this activity would start earlier than the projected start time.

It is therefore not critical. In this scheme, if more than 1 hour were required, it would have little bearing on the runway repair time. In addition, the runway can be utilized prior to completion of all marking.

(11) General Comments

One item not considered in the Tyndall testing is the keen coordination that an activity of this type must have. This is true with the present BDR procedure as well as this suggested procedure. Test 1-1 encompassed several incidents where a lack of communication equipment resulted in delays. Coordination also derives from thorough familiarity of the sequence and importance of events by each team member. Coordination between the team chief, the select-fill stockpile, the crater sites and the runway cleaning crews is essential. This is particularly true where equipment is shared by activities and where equipment must be pulled from non-critical activities to critical activities by the team chief as required. Tactical hand radios represent the easiest solution to this problem, and would be a small investment in comparison to the benefits that could be derived from improved coordination.

b. Required Changes to Implement Proposed BDR Package

(1) Equipment

(a) Change Summary:

As summarized from table 14 and shown in table 15, the requirement would be for the deletion of 8 pieces of heavy equipment and the addition of seven pieces of heavy equipment, 4 pieces of medium equipment and 13 pieces of light equipment. The original conversion to this package would be large, and a transition period from the current package to the proposed package would be requried, during which the Allis Chalmer 645's and the 20-ton cranes would be deleted by attrition or transfer into the base level organization.

(b) Equipment Costs

A survey of equipment dealers in the Albuquerque, New Mexico, area was conducted to determine the cost of the proposed equipment package relative to the current (1974) cost of the equipment listed in TA 010. Significantly, a 31 percent savings in time, based on the current four hour capability, could be realized with as little as 7 percent increase in the

Table 15

EQUIPMENT CHANGE SUMMARY

(Recommended Equipment Changes from Table 14)

Deletions

1 Crane, Truck Mounted, 20 Ton

7 Loader, Scoop, Tired, 2.5 CY, AC 645

8 Total

Additions

Heavy Equipment

3 Tractor, 400HP, Rubber-Tired, Michigan 280 RT

4 Loader, Scoop, Tired, 3 CY, AC 745

7 Total

Medium Equipment

1 Tractor, Industrial Wheeled

3 Truck, Dump, 5 CY

(9 @ Truck, 10 CY or delete 15 @ Truck, 15 CY)

4 Total

Light Equipment

3 Semi Trailer, Flat

3 Semi Trailer, Lowboy

3 Vibratory Compactor, Towed

1 Sweeper, Rotary, Towed

3 Conversion Fork Sets for AC 745 4-in-1 Buckets

13 Total

equipment package price. The cost of various options as a percentage of the current package cost is given in table 16. Because of the sharp increases in the cost of construction equipment, these figures are approximate only.

Table 16

PROPOSED PACKAGE COST, PERCENT OF CURRENT TA 010

	PERCENT
Proposed Package with 5 Yard Dump Trucks	
With Full Track Dozers	127
Without Full Track Dozers	107
Proposed Package with 10 Yard Dump Trucks	
With Full Track Dozers	136
Without Full Track Dozers	115

(2) Personnel

The proposed personnel realignment is given in table 17. No overall additional personnel would be required. Some minor juggling of specific operator AFSC's would be required, but this would amount only to a change of three 5XXXX positions to 55XXX positions and three 551XX positions to 551X1 positions. In addition, it is recommended that the team chief be upgraded to a captain position and the grader operator be upgraded to a Technical Sergeant position. The number of laborers per crater was reduced to three. The other three positions were converted to qualified equipment operators.

It was learned in Test 1-1 that direction of equipment from ground level is a necessity, particularly when equipment is working in a confined area where time is valuable. The three equipment directors would work with the more complex equipment -- the rubber-tired dozer, the fork-equipped loaders, and the graders. This increases the efficiency of each of these pieces of equipment and relieves the crater supervisor of the task of controlling the equipment from the ground, thus allowing him more freedom to plan and coordinate. It was noted that the time required for Test 1-1 would have been longer had not both the BDR team NCOIC and the crater team NCOIC been directing equipment from ground level. It was also noted that equipment not directed from the ground was less efficient. At times in Test 1-1, only those pieces of equipment under direct control from the ground were operating; the others were idle even though work remained to be done.

Table 17

PERSONNEL REQUIREMENTS, PROPOSED BDR PACKAGE

Rapid Runway Repair Team manning and organization for bases designated by the Major Command to receive a Rapid Runway Repair Kit:

Team	Personnel		AFSC	Proposed Personnel		AFSC	Change Rqmt., Remarks
Rapid runway repair team	Lt		5525	Capt	1	5525	Delete Lt, add Capt
(Pavements and grounds)	CMS/SMSgt	1	55191	CMS/SMSgt	1	55191	None
New center line crew	SSgt	1	553X0	SSgt	1	553X0	None
(Operations and maintenance)	Sgt	1	553X0	Sgt	1	553X0	None
	SSgt	1	552X4	SSgt	1	552X4	None
	Any Grade	1	5XXXX	Any Grade	1	5XXXX	None
Runway cleaning crew							
(Pavements and grounds)							
Rotary sweeper operator	Sgt/A1C	4	551XX	Sgt/A1C	6*	551XX	+2
Vacuum sweeper operator	SSgt/Sgt	2	551XX	SSgt/Sgt	2	551XX	None
Hauling crew supervisor	MS/TSgt	1	551XX	MS/TSgt	1	551XX	None
(Pavement and grounds)							
Front end loader operator	SS/Sgt	1	551XX	SS/Sgt	1	551XX	None
Dump truck operator	Any Grade	15	55XXX	Any Grade	18	55XXX	+3 (-6 of larger vehicles adopted)
(Any qualified operator)							
Crane operator	SS/Sgt	1	551XX		0		-1
Crane helper	Any Grade	1	551XX		0		-1
Tractor trailer operator	Sgt/A1C	3	551XX	Sgt/A1C	3	551XX	None
(Any qualified operator)							
Crater crews (3 each)							
(Pavements and grounds)							
Crater supervisor	1 MS/TSgt	3	551XX	1 MS/TSgt	3	551XX	None
Front end loader operator with forks	2 SS/Sgt	6	551XX	1 SS/Sgt	3**	551XX	-3
Grader operator	1 SS/Sgt	3	551X1	1 TSgt/SSgt	3*	551X1	Delete Sgt, add TSgt
Dozer operator (tracked)	1 SS/Sgt	3	551X1	1 SS/Sgt	3	551X1	(If Required)
Vibrating compactor operator	1 Any Grade	3	5XXXX		0		-3
Crater Laborers	6 Any Grade	18	Any AFSC	3 Any Grade	9	Any AFSC	-9
Dozer operator (Rubber Tired)	0	0		1 SS/Sgt	3*	551X1	+3
Equipment Directors	0	0		3 SSgt	9	551X1	+9
Matting Crews (3 each)							
(Pavements and grounds)							
Matting supervisor	1 MS/TSgt	3	551XX	1 MS/TSgt	3	551XX	None
Matting laying crew	16 Any Grade	48	Any AFSC	16 Any Grade	48	Any AFSC	None
	TOTAL						9 (-9 if larger dump truck adopted)

* would work on both crater and runway cleaning crew

** one would initially work in stockpile

If the requirement for the tracked dozers does not exist at a base, the operators positions can be deleted. In addition, if the larger dump trucks are utilized, a decrease of six operators can be realized in place of the increase of three.

The upgrading of the team chief position is a result of the minimizing of repair time through optimizing the use of equipment. To control simultaneously three crater crews, a runway cleaning crew, a stockpile and hauling crew and a paint crew requires more experience than was required in the previous AFM 93-2 repair scheme. This is especially true in view of the requirement to switch equipment from the cleaning team to the crater teams and back at the proper time. The upgrading of the grader operator reflects the importance of having an extremely skilled operator on this piece of equipment. The final grade of the repaired area is dependent completely upon this individual's skill. The quality and utility of the repair is in turn dependent directly on the final grade of the repair base course.

SECTION VI

TEST 1-4

1. OBJECTIVES

The primary objective of Test 1-4 was to investigate the feasibility of using various 750 pound bomb crater repair techniques on small craters similar to those expected to result from an attack with small penetrating weapons. Other objectives were to qualitatively examine various equipment mixes, to preview certain repair techniques and discover any serious shortcomings before the techniques were used on large craters and to gather data on small craters in a sand subgrade.

2. PROCEDURES

To achieve the above objectives, four small craters were made by statically detonating 25-pound C-4 charges at a depth of burst of 48 inches beneath areas of pavement that had not been damaged in Tests 1-1 and 1-2. Repair of each crater was done by a separate method. Crater 1-4 NE was repaired in a manner similar to that prescribed in AFM 93-2, utilizing AC 645 loaders and a motorized grader. Crater 1-4 NW was repaired by clearing away the debris with an AC 745 loader and a 280 RT rubber tired dozer. The crater was then backfilled with a regulated-set cement cellular foam and capped with a regulated-set slurry. Crater 1-4 SW was backfilled with debris and cleaned with the same equipment as 1-4 NW. The subgrade of debris was compacted with a towed vibratory compactor to within 1 foot of the surface and a regulated-set cement slurry was then used as a capping. Crater 1-4 SE was backfilled with debris similar to 1-4 NE and 1-4 SW. The last 1 foot of fill consisted of a course uniformly graded aggregate which was infiltrated with a regulated-set cement slurry.

3. INDIVIDUAL CRATER TESTING

a. Crater 1-4 NE

(1) Repair Procedure.

Crater 1-4 NE was repaired in accordance with AFM 93-2. A debris backfill was utilized with a select fill base course and an AM-2 capping.

All work was done with two AC 645 loaders and a motorized grader. The process included use of the two AC 645's to shove the upheaved pavement into the crater and to lift up and carry away the upheaved pavement that would not fit into the crater. The uplifting was accomplished from inside the crater (figure 65). By working inside the crater, compaction of the debris backfill was accomplished with the rubber-tired AC 645's. Following the completion of the backfilling and the removal of all upheaved pavement, select fill was hauled from a nearby stockpile and placed in the repair. Compaction of this material consisted of the wheel rolling by AC 645's and the passage of the motorized grader. To increase the wheel loading of the 645's, select backfill was carried in the scoop. The 645's were used to drag the AM-2 matting into place. This matting had been constructed in a small patch, measuring 30 feet by 37.5 feet, although a full patch width is required for aircraft operation.

Figure 65. Test 1-4 NE, AC 645 Removing Upheaved Pavement from Inside Crater

(2) Equipment and Time Results.

A table of activities is listed in table 18. Several items are

noteworthy. Total equipment usage time was 2 hours and 52 minutes for the AC 645's and 1 hour and 21 minutes for the grader. The total repair time was 2 hours and 30 minutes. This is not a representative minimum time, since the equipment operators were told that a proper repair with proper use of equipment was the objective, not minimum time. No particular advantage was gained by utilizing two AC 645's as opposed to one. The total time during which both 645's were working was only 51 minutes. A portion of this time was spent with mechanical problems on the reverse gear of one of the loaders. The use time of the AC 645's was also increased by the inadvertent over-filling of the crater with debris (figure 66). This required pushing material out of repair area. In addition, it created the presence of large pieces of concrete debris near the subgrade surface. This resulted in difficulties in leveling and compacting the subgrade.

Table 18

TEST 1-4 NE, ACTIVITIES LOG

0821	Begin with two AC 645's w/4-in-1 buckets
0826	One AC 645 in use
0829	Working inside crater with one AC 645
0830	AC 645 #2 working outside crater
0832	Crater filled to within 1' of top
0842	Two AC 645's working in conjunction, one inside, one outside
0900	Grader started
0905	One AC 645 cleaning up
0919	Grader pushing in fine debris and cleaning up
0927	Grader cleaning, one AC 645 shaving asphalt to lower lip, also attempting to remove some debris from inside crater
0934	One AC 645 starting to haul select fill
0939	One AC 645 Back-dragging surface and running through center for compaction
0945	One AC 645 standing by with select fill, the other attempting to compact
0955	Both AC 645's idle, hand work being done in crater
0957	Begin dumping select fill into crater
1000	Grader begins grading in crater
1006	One AC 645 compacting select fill
1011	Grader putting final grade on select fill
1021	Grader finishes, but also has hydraulic problem with blade
1027	One AC 645 again compacting
1032	One AC 645 dragging 30' x 37.5' AM-2 patch up to crater
1033	One AC 645 compacting is waved off
1039	Hand work on cleaning started
1042	Hand work ends
1051	Patch pulled into acceptable position, end test

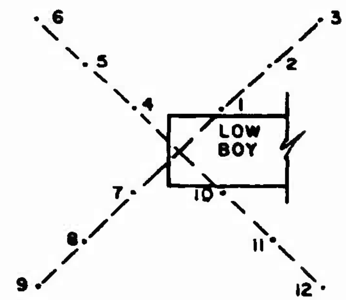
Figure 66. Test 1-4 NE, Crater Overfilled with Debris Requiring Removal

(3) Test Loading.

Loading tests performed on the crater (figure 67) showed marginal compaction. The use of the large concrete debris in a crater repair of this since probably aids in the load carrying capability, but hindered the compaction process. The base course had a k value of only 168 pci, with a CBR of only 11.5. The compacted subgrade could not be plate loaded due to the concrete chunks present. The dry sandy nature of the debris and the dry state of the base course was responsible for a lower than normal average CBR reading of nine.

(4) Crater Size Consideration.

The repair of craters of this size in asphalt or unreinforced concrete can be effectively handled by one loader equal in size to or larger than an AC 645 and one motorized grader. This is due to the small volume of crater and debris, as seen in section IX and figure 68. The crater had a volume equal to only 4 percent of a 750-pound bomb crater in clay or 12 percent of a 750-pound bomb crater in sand. The debris volume was similarly small, being only 4 percent of the volume of ejecta and upheaval from a 750-pound



3 RADII @ 6'-10'-14'

(all deflections are given in ft)

LOAD POINT	93PSI	150 PSI	217PSI	283PSI	349PSI	468PSI
1	.000	.003	.002	-.001	.000	-.005
2	.000	.001	.001	-.002	-.005	-.004
3	.003	.005	-.001	-.003	.000	-.008
4	.006	.001	.000	-.006	-.002	-.005
5	-.002	-.003	-.002	-.005	-.006	.000
6	.008	.005	.005	.003	.003	.000
7	-.005	-.006	-.003	-.009	-.004	-.009
8	-.008	.001	-.001	-.001	.000	-.010
9	-.006	-.010	-.006	-.011	-.011	-.014
10	.018	.018	-.014	.014	.010	.009
11	.003	.003	-.004	-.006	-.006	-.007
12	-.003	-.003	-.008	-.005	-.012	-.010

Figure 67. Deflection Basin Study, AM-2 Load Test, Crater 1-4 NE

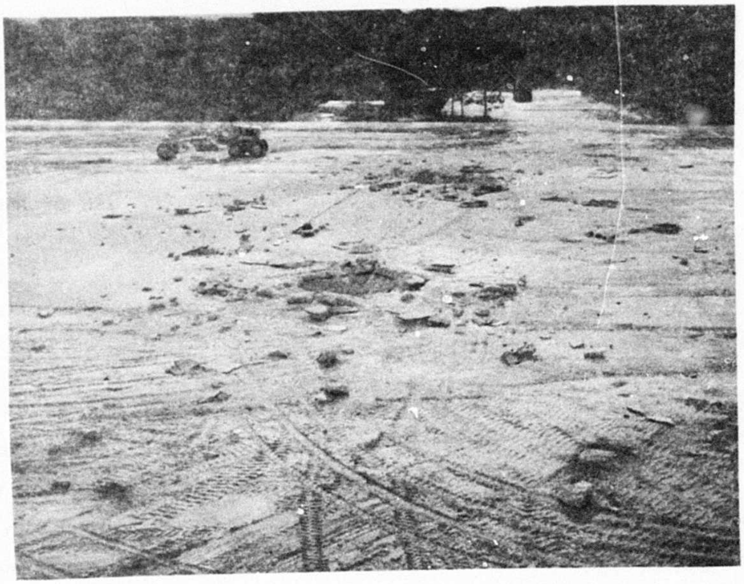


Figure 68. View of Craters 1-4 NE and 1-4 NW Prior to Repair

bomb crater in sand. The repair area is relatively larger, being 14 percent of that experienced in Tests 1-1 and 1-2, and 22 percent of that in Test 1-3. Additional equipment requirements would be a water tank truck and a towed vibratory compactor to ensure the compaction quality of the base course material.

(5) Alternate Backfill Procedures.

Because of the small volume of craters such as this, it would be practical from several standpoints to utilize only select backfill. An increase of only 10 yards or less would be required for each crater. This additional requirement would be justified in view of the added compaction that could be obtained by utilizing a material of known engineering qualities.

(6) AM-2 Patches on Small Repairs.

The use of the 30- by-37.5-foot mat is an example of the flexibility in size of AM-2 patches. However, a mat this size could not be used in runway repairs. The mat must extend the full width of the repaired runway. This alleviates the danger of aircrat tires being blown out on the edge of the matting and also ensures minimum differential roughness or elevation

between the main gears. A minimum of 40 feet between ramps has been established as a minimum spacing of mats, and can be interpreted as the minimum mat length as well. It appears that until a broad study of aircraft BDR roughness interaction is completed, the patching of small craters will remain a mystery. Whether or not aircraft can tolerate the use of multiple small AM-2 patches is unknown.

b. Crater 1-4 NW

(1) Repair Procedure.

The repair of crater 1-4 NW consisted of removal of all upheaval and debris from the vicinity of the crater with the 280 RT rubber-tired dozer and and AC 745 loader (figure 69). Once this work was completed the crater backfill was entirely foamed with regulated-set cement, while the cap was a regulated-set cement slurry. This test was the first attempt at using the regulated-set cement both as a capping and as a backfill material, and as such provided valuable information for the tests in Phase II of the Tyndall BDR testing. Information on the regulated-set cement properties and its use in this test are covered in section VIII which describes regulated-set cement.

Figure 69. Test 1-4 NW, 280 RT and AC 745 Working on Crater Repair

(2) Equipment Results.

An equipment package consisting of the 280 RT and AC 745 loader was not well suited to this type repair. The loader alone would have been adequate, especially in view of the requirement to move all material from the crater. The process of removing the lip without being able to push it into the crater is time consuming and would require rather specialized equipment, similar to that used by the United Kingdom (ref. 23). The relatively small size of the crater, as noted in the repair procedure for crater 1-4 NE, limits the useful size of equipment.

(3) Surfacing Failure.

Expansion and contraction phenomena in the mass of regulated-set led to failure within weeks (figure 70). This is discussed in section VIII.

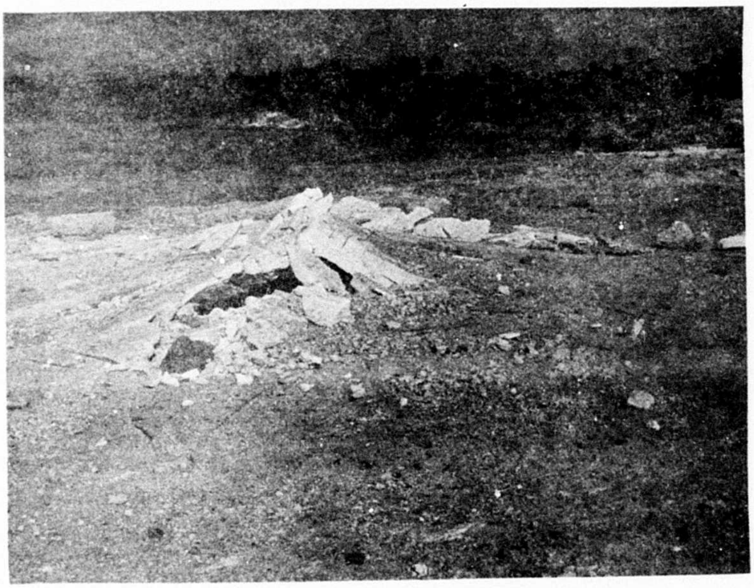


Figure 70. Test 1-4 NW, Failure of Regulated-set Cement Cap

c. Crater 1-4 SW

(1) Repair Procedure.

The repair of crater 1-4 SW was accomplished by using the AC 745 loader and the 280 RT rubber-tired dozer for cleaning up debris and backfilling the crater. In addition, the debris backfill was well compacted with the use of a towed vibrating compactor. No record of equipment usage time was kept, and observations on equipment suitability parallel those for the repair of crater 1-4 NW. Upon completion of the backfilling, a 12-inch regulated-set slab was placed. This slab was pumped on two separate days due to equipment shortcomings. Use of reg-set in this test is covered in section VIII.

(2) Test Loading.

The section was load tested after completion. The equipment difficulties had resulted in a layered pavement system over the center of the repair. The actual loading point was over the originally prepared subgrade rather than the center of the repaired crater, as would have been desirable. The load-deflection curve is shown in figure 71.

d. Crater 1-4 SE

(1) The repair of crater 1-4 SE consisted of the backfilling of the crater with debris up to 1 foot below the original pavement surface. Compaction was only by wheel rolling with the one AC 645 loader utilized in the repair. As mentioned before, this one piece of equipment was satisfactory for the limited amount of debris and upheaval caused by the 25-pound C-4 charges.

(2) The debris subgrade was covered with a 1-foot thick course of uniformly graded aggregate in the 0.5 to 0.75-inch size range. Reg-set cement slurry was infiltrated into this to form a type of concrete. This reg-set operation is covered in section VIII. Loading of the surface was successful, with figure 71 showing the load-penetration relationship.

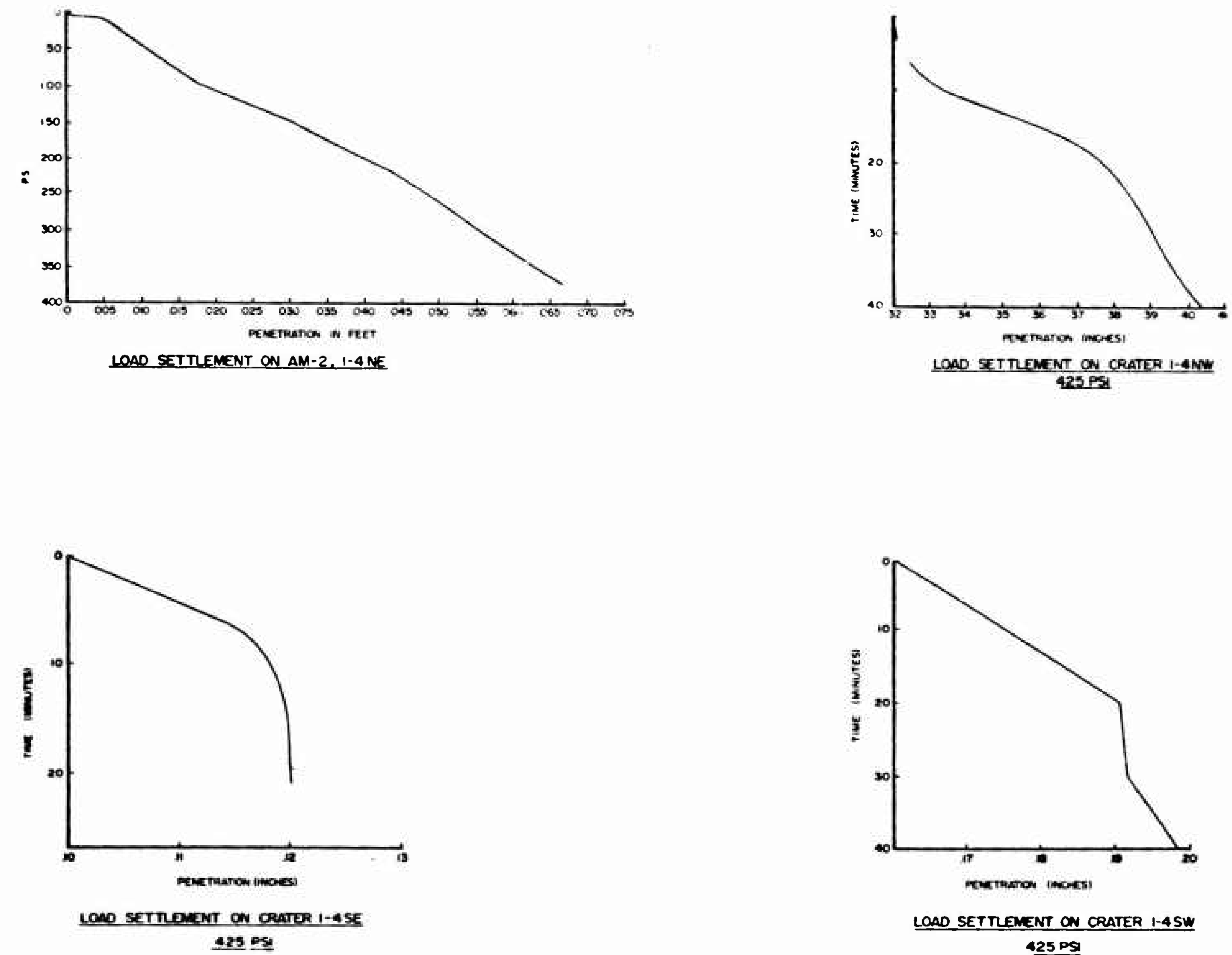


Figure 71. Test 1-4, Loading Curves

SECTION VII

TEST 2-1

1. OBJECTIVES

The primary objective of Test 2-1 was the full scale testing of a structural BDR technique developed by Texas Tech University for AFWL. This technique involves the use of modules constructed from Polyvinyl Chloride (PVC) pipe. Both the expediency of the repair procedure and the engineering properties of the final product were tested. Secondary objectives of Test 2-1 included careful study of the use of regulated-set cement (reg-set) on a larger scale than it had been previously used, the mass use of cellular foam reg-set (foam reg-set) as a backfill material and the use of a large mass of neat reg-set slurry as a capping material.

Portions of this test are described in references 18 and 19. The discussion of the test as contained in this section deals primarily with the PVC modules and the test as an entity.

2. REGULATED-SET CEMENT

Data and specifications pertaining to the reg-set used for Tests 1-4, 2-1 and 2-4 are contained in appendix XII, a set of preliminary and experimental data supplied with the reg-set by the manufacturer, Lone Star Cement Company, Demopolis, AL. Additional material required with reg-set were a protein base organic foaming agent and citric acid. The latter was used as a retardant.

Prior to testing at Tyndall, several problems were known to exist with the use of reg-set. Most of the work done with reg-set prior to testing at Tyndall is contained in a report to be published by AFWL documenting contract efforts of the U.S. Army Waterways Experiment Station (WES). Section VIII of this report describes and analyzes reg-set and its use in Tests 1-4, 2-1 and 2-4.

3. PVC MODULE TECHNIQUE

The technique developed by Texas Tech University is documented in reference 18. Figure 72 shows the basic configuration and dimensions of the PVC modules. Figure 73 shows the manner in which the modules were placed to fill

an optimum volume of a 750-pound bomb crater. A preliminary test run at WES utilized modules of different lengths in a somewhat smaller crater (figure 74).

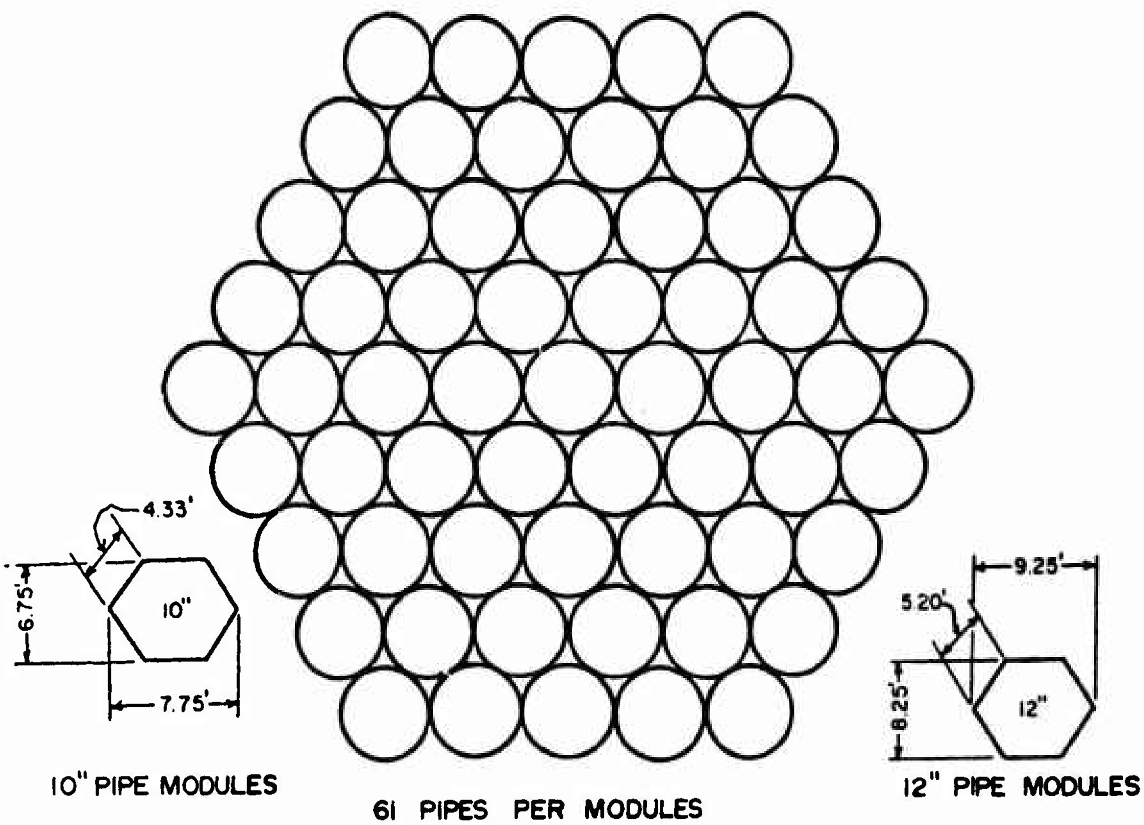


Figure 72. Configuration and Dimensions of 61 Pipe PVC Modules

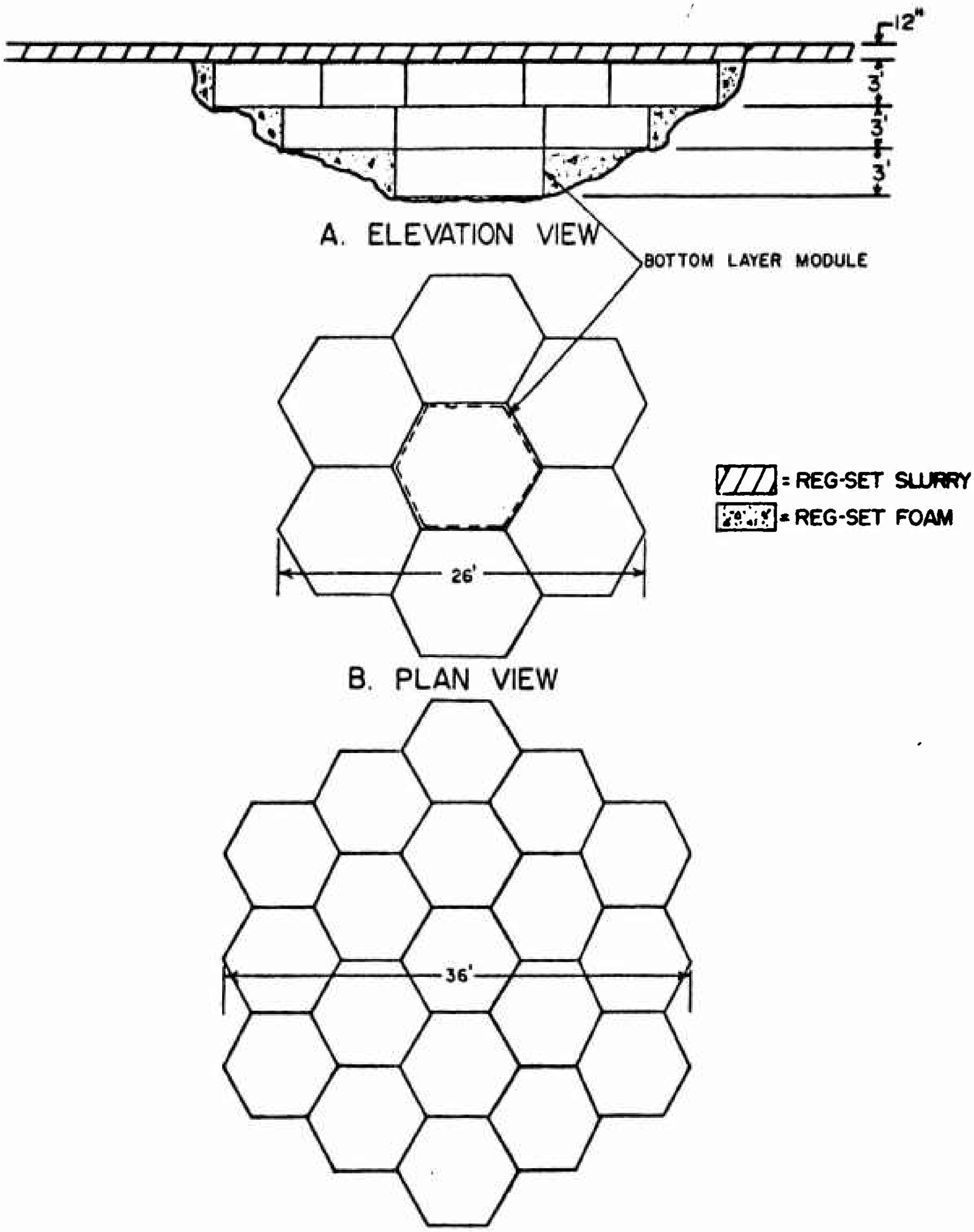


Figure 73. Tyndall AFB Test 2-1 Repair Configuration

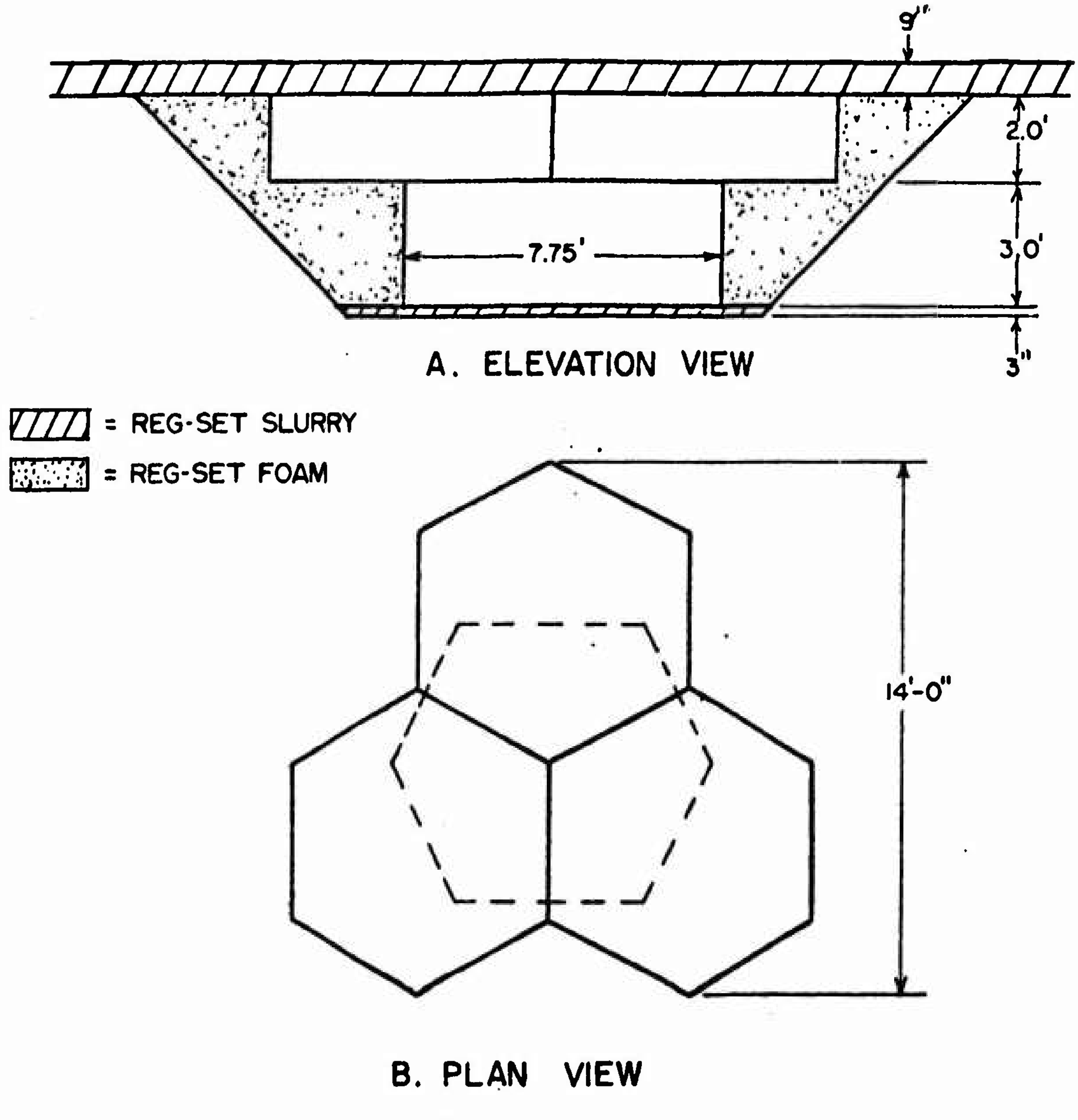


Figure 74. WES Repair Configuration

The modules were selected by Texas Tech for the role of crater backfill because of their simple construction, predictable engineering properties and exceptionally light weight. Further, they could be constructed from various sizes of commercially available PVC irrigation pipe. The modules weigh about 900 pounds if constructed of 10-inch diameter pipe and about 1200 pounds if constructed of 12-inch pipe. The 10-inch pipe module, 3 feet in thickness, occupies some 5.07 CY, and the 12-inch pipe module occupies 6.08 CY. This yields a backfill weight for the 10-inch pipe modules of about 6.6 PCF, and about 7.3 PCF for the 12-inch pipe modules, exclusive of reg-set or other grouting material.

As used in Test 2-1 (figure 73) the total module backfill system (without reg-set considered) weighs only 26,700 pounds and occupies some 144.9 CY. Figure 75 shows several of the modules being transported to the site. If properly secured, the weight is such that the modules could be stored and transported on a single large semi-trailer.

The basis for the strength requirements of the modules and the size of the individual modules was the ability of a single module to sustain a 50,000-pound load concentrated in a 102-square-inch area without significant deflection. This is approximately equivalent to an F-111 gear load on the foot print of an F-4 aircraft, a hypothetical but necessarily rigorous criteria. The module sizes were based upon the use of canvas at the bottom of the crater to help avoid punching shears. By utilizing a hard slurry floor such as used at Tyndall (figure 76), modules smaller than were actually used could be placed; possibly modules small enough to be placed by hand. These smaller modules could allow a maximum of crater volume to be filled with modules. A module fill volume of 75 to 80 percent was sought at Tyndall.

The basic layout and use of the modules in Test 2-1 (figure 73) was designed specifically for at 750-pound bomb crater similar to that created in Test 1-1. A layer of slurry was first poured in the crater as a foundation. Following this, a layer composed of one 12-inch PVC module 3-feet in thickness was placed. The area between the module layer and the crater wall for this and the succeeding two layers was filled with foam reg-set. Before placing the seven 12-inch PVC pipe modules of layer two, and subsequently the 19 PVC pipe module layer three, 2-inch reg-set slurry layers were poured to ensure proper load carrying contact between the modules.

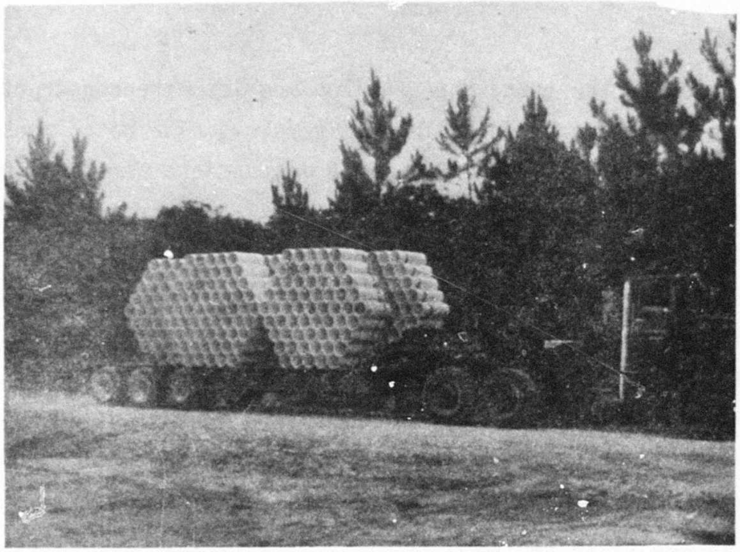


Figure 75. Test 2-1, PVC Modules Being Transported to the Repair Site

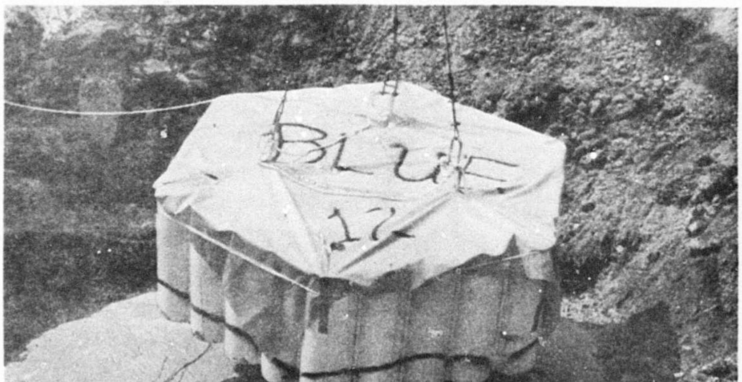


Figure 76. Test 2-1, Reg-set Slurry Floor Added for Strength

4. TEST PREPARATION

a. Modules

(1) Prior to the test, the required modules were constructed by AFCEC under the direction of Texas Tech University. The basic construction technique is covered in reference 18. Some innovations were made by AFCEC which allowed more rapid construction. Figure 77 illustrates a portion of the construction process. It involves the accurate cutting of the PVC pipes to length (3 feet) and the gluing together of 61 of the pipes in the configuration shown in figure 72 to make each module. While the modules were constructed at Texas Tech with the pipes vertical, AFCEC personnel chose to construct the modules in the horizontal position, thus effecting a significant time advantage. Altogether 27 modules were constructed for the test, although only 26 were fit into the crater.

(2) Construction of the modules at AFCEC peaked at the rate of seven per day for a three-man crew, or a rate of 3.4 manhours per module. Cost of materials was $64 per CY for tests conducted at Tyndall. It was estimated that this cost would drop to $40 per CY for quantity buys of materials suitable for this application.

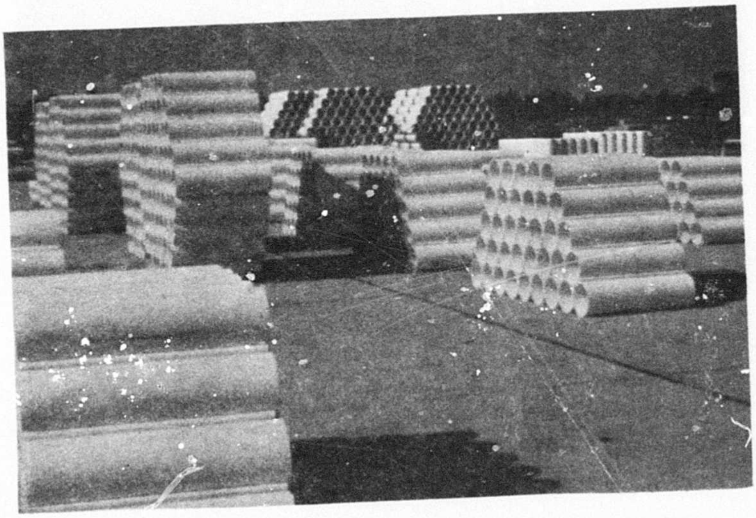


Figure 77. Test 2-1, PVC Modules Under Construction

b. Crater and Site

(1) The detonation for crater 2-1 was the first attempt at using a previously repaired area. A Gradall was used to dig a weapon placement hole to a depth of 12 feet. A plywood casing was then inserted and backfilled into place (figure 78). The 750 pound weapon was placed in the casing and detonated. The resulting crater was smaller than those created in Tests 1-1 and 1-2, as a consequence of several factors. These possibly included the lack of confining pavement, the higher unit weight of the debris backfill from Test 1-2, the interlocking structure of the debris backfill, and the presence to only loosely compacted backfill around the plywood casing. To make the crater conform to the designed test module system, it was excavated on the sides and backfilled on the bottom, creating profiles similar to those of craters 1-1 and 1-2 (appendixes III and IV).

(2) It is important to understand that PVC modules could be used with any size crater. The control of variables in Test 2-1 was the primary reason for excavating rather than using fewer or differently shaped modules.

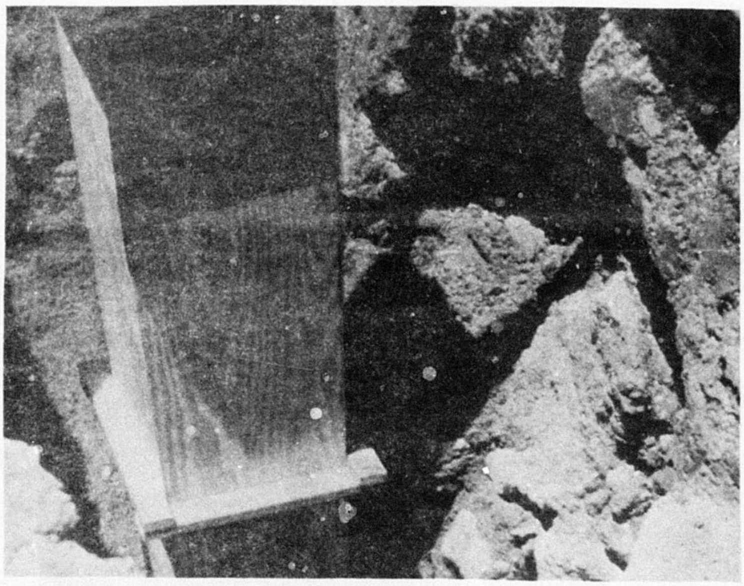


Figure 78. Test 2-1, Plywood Casing for M117 Weapon

(3) Figures 79, 80 and 81 show the original crater, the reshaped crater, and the crater with modules and formwork located ready for repair. It was decided to minimize excavation by using the existing repair surface as the base elevation for the reg-set cap rather than a plane 12-inches below the original pavement surface.

c. Reg-Set Forms.

An integral part of the test was the reg-set cap. Reg-set is covered in detail in section VIII. To facilitate the placement of the reg-set cap, formwork for the surface was prefabricated with 10-foot lanes and a maximum length of 70 feet. Figure 82 shows this formwork being filled. The form was shortened to 50 feet to compensate for the unexpectedly large volume of reg-set used in the backfill process.

d. Equipment.

Equipment required for the placement of reg-set in Test 2-1 is covered in section VIII. During actual testing, the only equipment used to support the PVC module placement was the semi-trailers and truck tractors required to transport the modules and a Gallion 90 hydraulic crane. Other equipment was used prior to testing to clean around the crater and to excavate and fill as required.

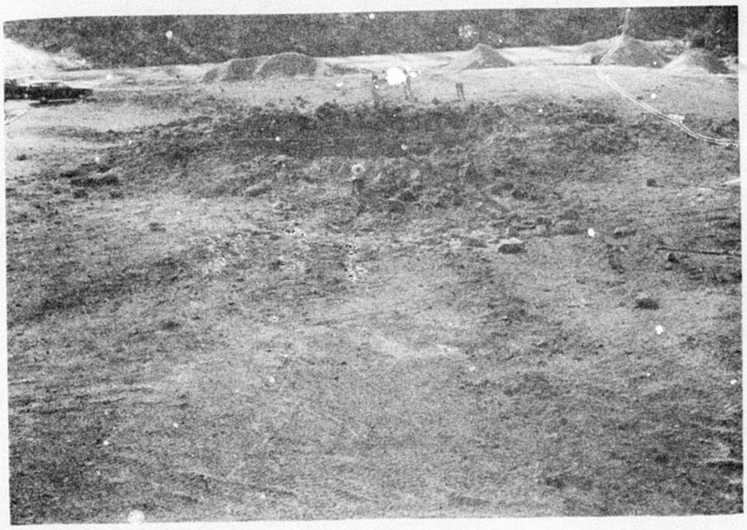


Figure 79. Test 2-1, Crater Prior to Preparation for Test

Figure 80. Test 2-1, Crater Following Area and Lip Cleanup and Internal Shaping

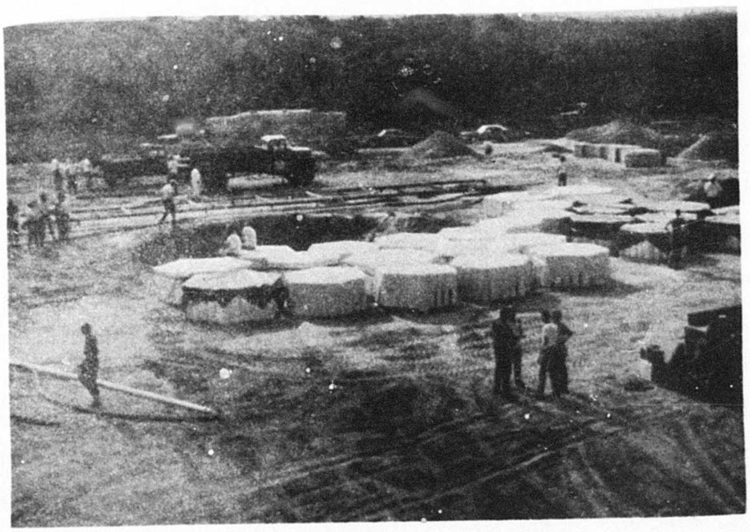


Figure 81. Test 2-1, Modules and Formwork at Site Prior to Test

Figure 82. Test 2-1, Formwork being Filled with Reg-Set Cement Slurry

5. TESTING

a. Repair Operation

(1) Figure 83 supplied by Texas Tech University shows that institutions concepts of the work required for the PVC modular backfill repair technique. Since the test area had been previously repaired, an entire test similar to 1-1 was not possible. Only that portion of work enclosed within the dotted line was actually performed. Figures 84A through 84H show the operation in progress, up to the cap formwork.

(2) Essentially the test was divided into three operations. Operation one was the placing of the modular backfill and foam backfill. Operation two was a transition from backfill to capping and included the placement of the forms required for capping. Operation three consisted of the entire placement of the cap. Table 19 shows the proposed manpower requirements for the test while table 20 shows the actual manpower usage. The suggested requirements hinge more on the desired rate of flow of reg-set than upon any other factor; the flow being the critical factor in determining the time to repair.

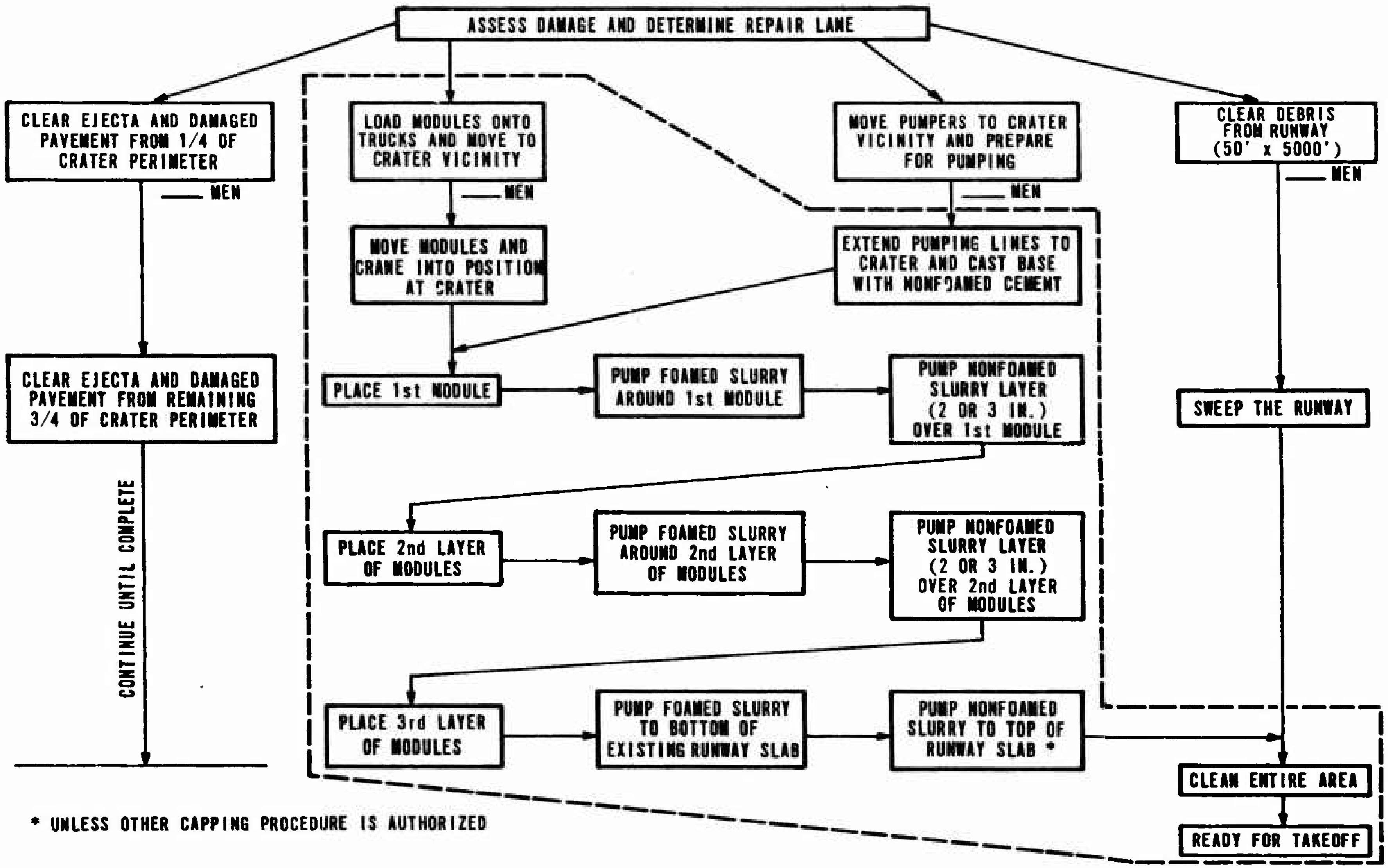
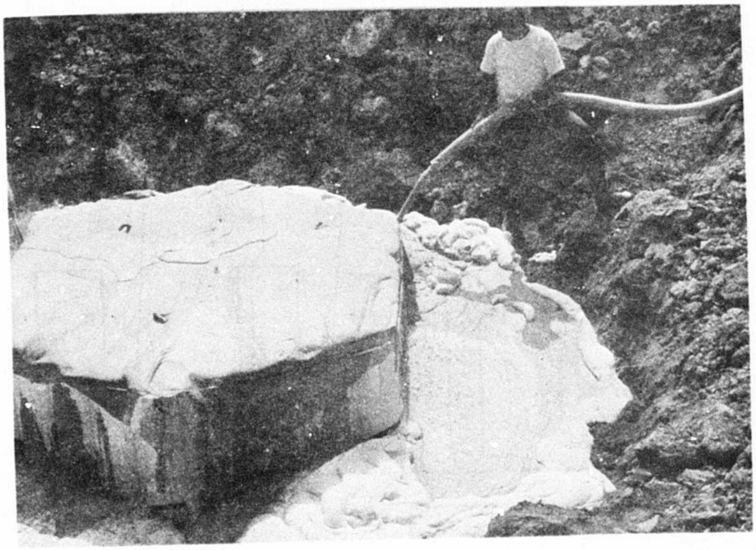


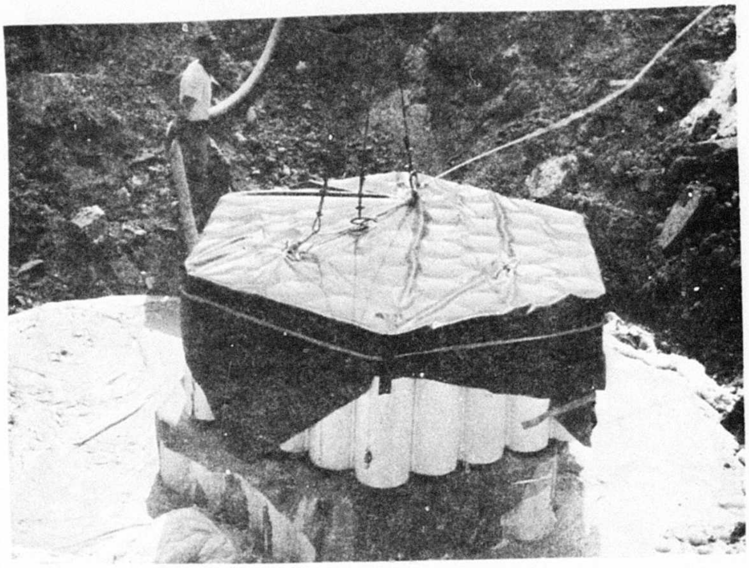
Figure 83 - Test 2-1, Work Requirement Flow Chart

A. Placing Slurry Floor



B. Foam Reg-set Being Placed Around One Module Bottom Layer

Figure 84. Test 2-1, Backfilling Procedure

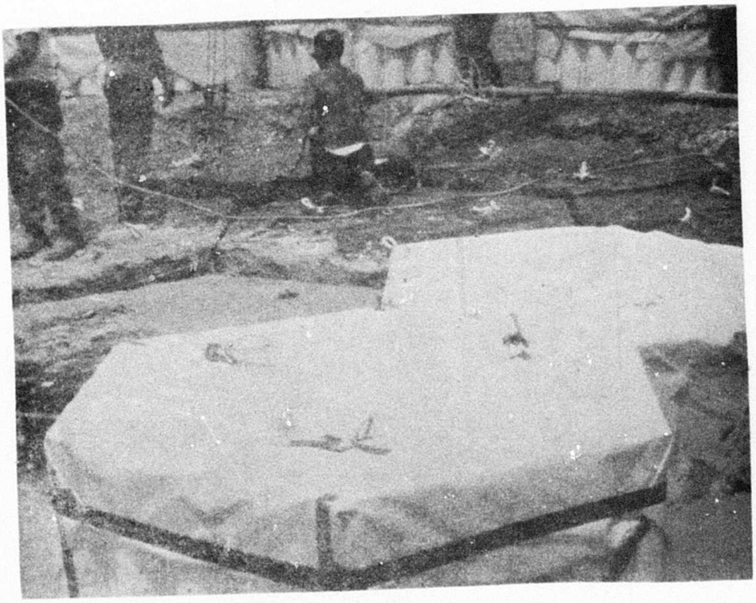


C. First Module of Second or Middle Layer Being Placed on Slurry Cap of One Module Bottom Layer

D. Foam Reg-set Being Placed Around Modules in Second or Middle Layer

Figure 84. Test 2-1, Backfilling Procedure (Continued)

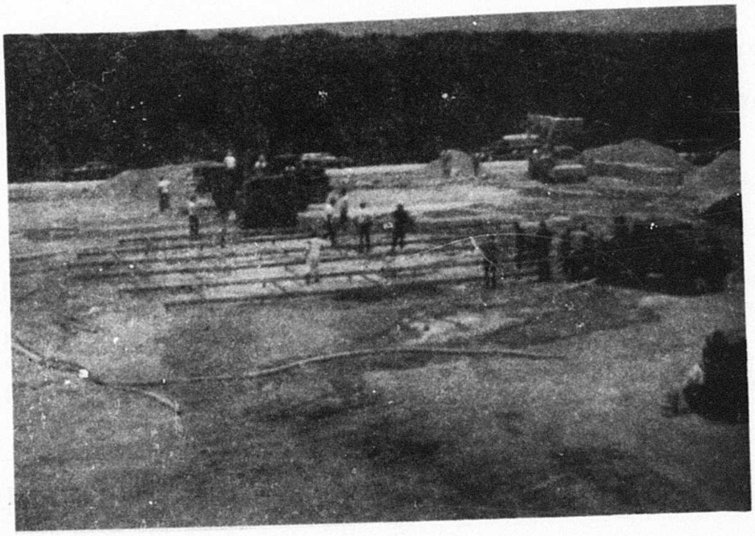
E. Placing Modules in Second or Middle Layer



F. Placing Modules in Third or Top Layer

Figure 84. Test 2-1, Backfilling Procedure (Continued)

G. Placing Final Module in Top Layer



H. Placing Formwork for Overlaying Reg-set Cap

Figure 84. Test 2-1, Backfilling Procedure (Continued)

Table 19

TEST 2-1, PROPOSED MANPOWER

	Pumps In Use		
	1	2	3
<u>Phase I, Backfill</u>			
NCOIC Repair and Crater	1		
NCOIC, Pumps	1		
Pump Operators	1	1	2
Pump Groundsmen	1	1	1
Hosemen	2	2	2
Crane Operator	1		
Crane Groundsmen	3		
Pumper-Tanker Operator	1		
Total Required, Phase I	11	15	20
<u>Phase II, Transition</u>			
NCOIC, Repair and Crater	1		
NCOIC, Pumps	1		
Pump Operators	1	1	2
Pump Groundsmen	1	1	1
Carpenters	6		
Pumper-Tanker Operator	1		
Total Required, Phase II	11	13	16
<u>Phase III, Cap</u>			
NCOIC, Repair and Crater	1		
NCOIC, Pumps	1		
Pump Operators	1	1	2
Pump Groundmen	1	1	1
Hosemen	3	3	3
Screedmen	2	2	2
Labor w/Screed Team	2	2	2
Waterman	1		
Pumper and Tanker Operator	1		
Total Required, Phase III	13	22	32

Table 20

TEST 2-1, ACTUAL MANPOWER USED

PHASE	I	II	III
NCOIC	1	1	1
Operators, Pump #1	3	3	3
Operators, Pump #2	3	3	3
Operators, Pump #3	3	3	3
Hose Team #1	3	3	3
Hose Team #2	3	3	3
Hose Team #3	3	3	3
Operator, Crane	1	1	
Groundmen, Modules	4		
Operator, Water Truck	1	1	1
Assist as Required	2		
Hose Layout		1	
Carpenter Form Team		14	
Screed Team #1			4
Screed Team #2			4
Hosemen, Water Cure			2
TOTAL	27	27	27

In addition, three employees of the trucking company from whom the field bins were rented operated the pneumatic feed systems. Two employees of the Waterways Experiment Station, WES, also participated in operation of pumps.

(3) The suggested usage would require as many as 32 men for the portions of the repair accomplished. However, by shutting down one of the pumps, the load for all three operations could be fairly well balanced. The actual usage was based on a uniform requirement for all three operations and the operation or possible operation of three pumps was provided for.

(4) Table 21 presents a time-activity summary of the portion of the modular fill repair technique studied. Figure 85 breaks the test into six activities. Most meaningful is the evidence that the total placement of the modules took only 1 hour and 49 minutes. The placement was delayed at times while waiting for the reg-set placement to catch up and cover the tops of module layers 1 and 2. It took 1 hour to place the 18 modules located in the top or third layer, a average of 3-1/3 minutes per module. Addition of a second crane would, of course, halve the total module placement time.

(5) While the time to place each module does not seem to be excessive in view of the average volume of the modules, 5.4 CY, it will be recalled from Test 1-1 that the backfilling is not the most significant BDR problem. The problem of pavement removal is not solved by this technique; in fact, it is made more difficult since the pavement and soil cannot be pushed into the crater and so easily disposed of.

(6) The engineering properties of the backfill system are known, an advantage; however, to avoid long term settlement the crater wall and floor must be removed, as discussed in section IV on Test 1-2. This creates a new operation not required for a debris backfill method, particularly when a flexible cap is designed to withstand settlements and surface deflections.

(7) One major problem developed in the placing of the modules. Several of the modules in layer 2 could not be placed exactly level. As a result, the top of layer 3 was extremely uneven, with the difference (figure 86) being as great as 1 foot. While this wasn't critical for load carrying capability, it did create a requirement for approximately 30 percent more reg-set in the crater cap.

b. Load and Materials

(1) During the test, temperature sensitive thermocouples were implanted as shown in figure 87, a continual record of the heat generated by the curing reg-set.

Table 21

TEST 2-1, ACTIVITIES LOG

0947	First reg-set delivered to crater, two pumps
0954	Two pumps cut off
0956	Two pumps pumping into crater
1000	Pumping of slurry base complete, two pumps cut-off
1001	Module #1, Layer #1 in place
1002	Two pumps started, foam on west, slurry on east
1010	Module #1, Layer #2 in place
1022	Reg-set up to top of Layer #1
1027	Two pumps cut off
1040	Two pumps started with foam
1045	Module #7, Layer #2 in place
1050	Module #1, Layer #3 in place
1118	Reg-set up to and over Layer #2
1121	Reg-set begin pumping between Layer #3 modules
1150	Module 18, Layer #3 in place, Module 19 eliminated
1233	Layer #3 gaps full, two pumps cut off
1236	Forms being moved into place over repair
1257	All forms in place
1323	All forms sized and leveled, begin placing polyethylene
1355	Polyethylene in place, 2 pumps started
1402	Two pumps cut off, polyethylene ineffective
1412	Two pumps started, forms still being repaired
1420	Screeding begins
1434	Screeding of center lane complete
1448	Screeding of center west lane complete
1457	Screeding of far west lane complete
1457	One pipe broken and corresponding pump cut-off
1459	Two pumps again running
1505	One pump on broken pipe cut-off
1511	Screeding off far east lane complete
1520	Premature set-up experienced on south end of center east lane, final pump cut off
1524	Screeding complete, cleanup begins
1551	Repair complete

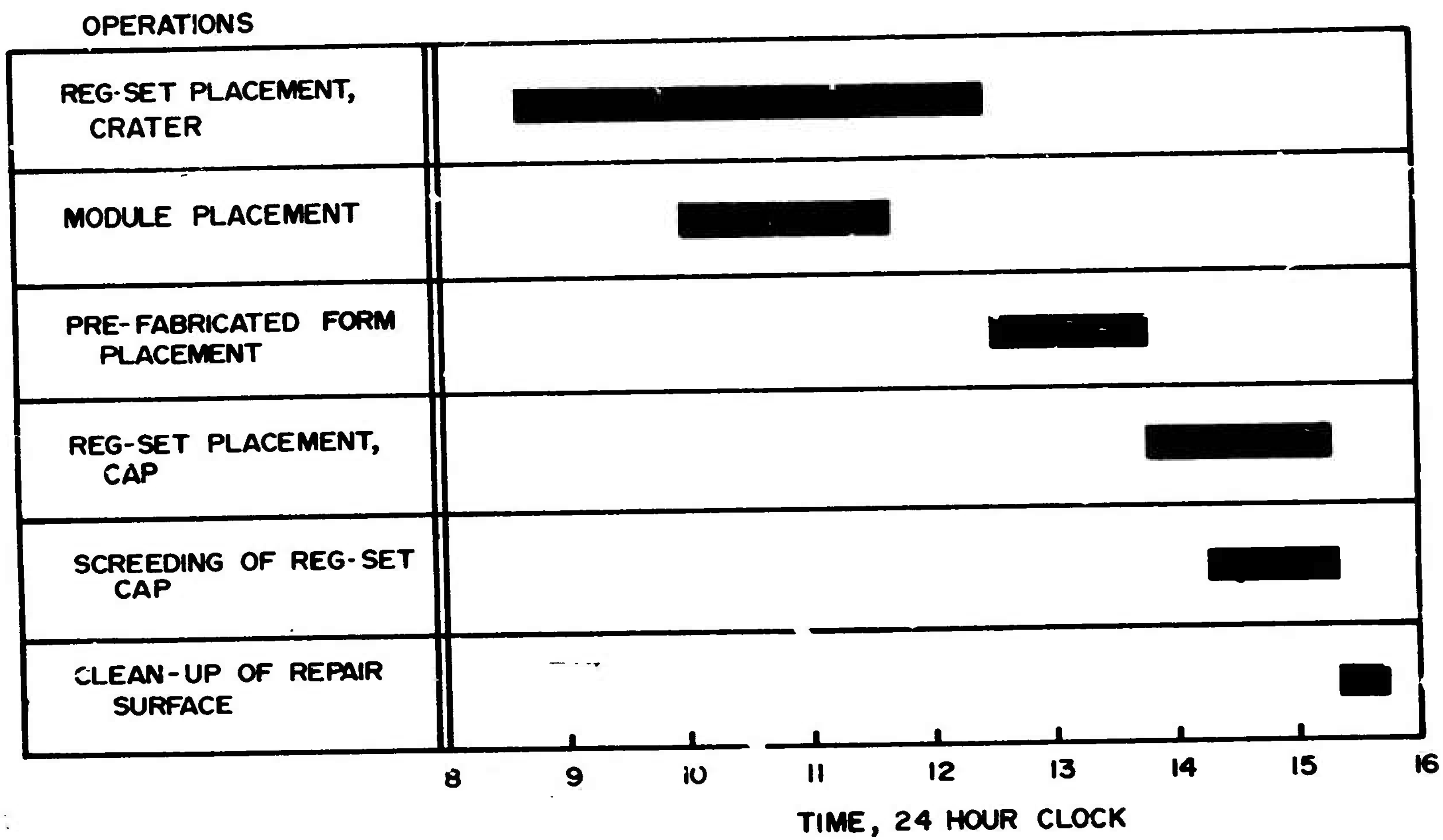


Figure 85. Test 2-1, Time Sequence Bar Chart

Figure 86. Test 2-1, Extreme Uneveness, Top or Third Layer

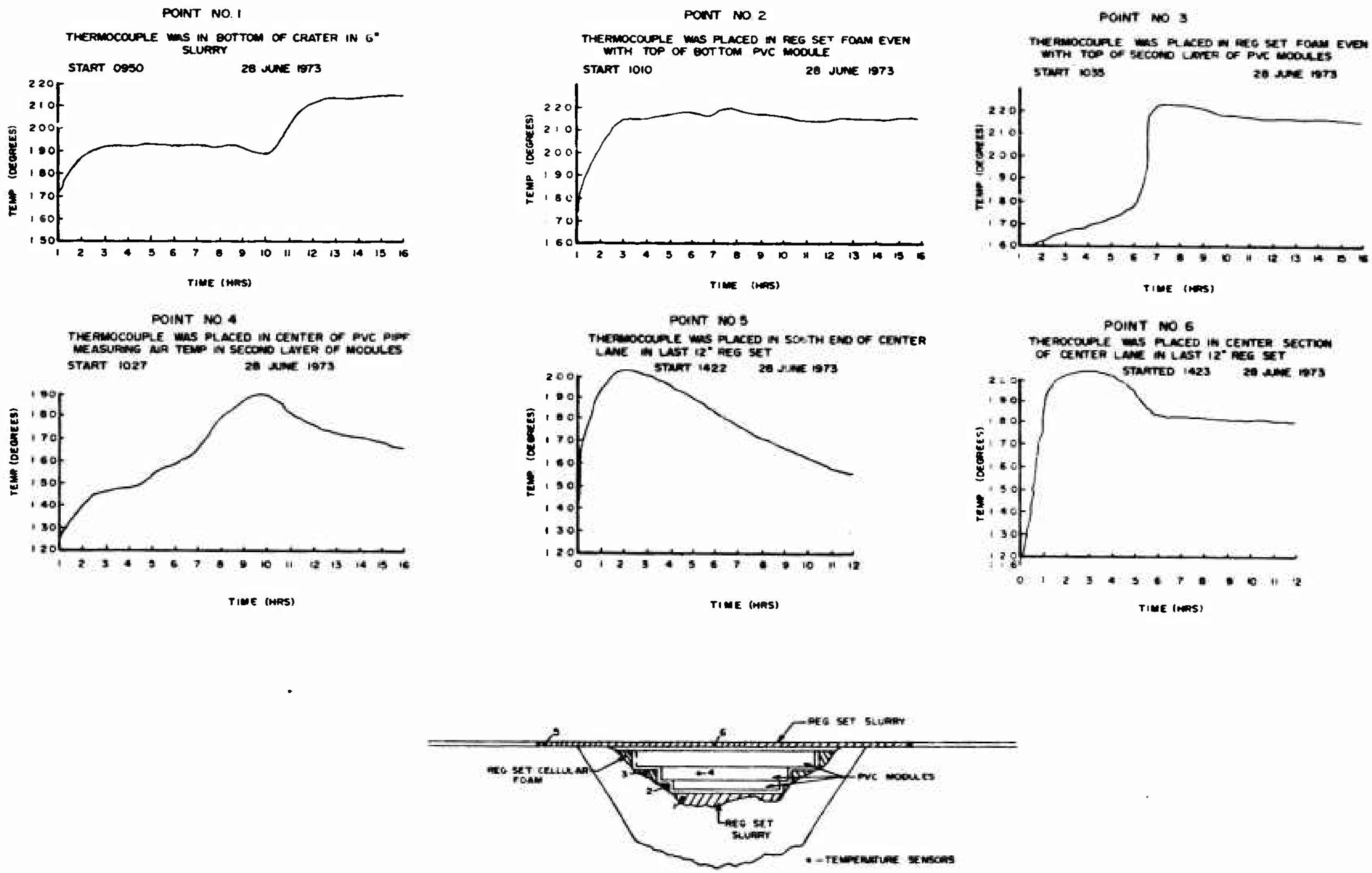


Figure 87. Test 2-1, Continuous Temperature Recording of Emplanted Thermocouples

The importance of the dramatic temperature rises became clear when the loading of the test section was attempted. As in the other tests in this series, a load of 50,000 placed on a 12-inch diameter plate was to be used along with a load cart carrying 29,000 pounds on an F-4 wheel. Problems begin as soon as the loaded lowboy trailer was backed onto the repair. Even though 2-by-8-foot planks of AM-2 matting were utilized to prevent concentrated loading prior to testing (figure 88), failure begain almost instantly. Large circumferential cracks (figure 88) occurred along with the release of steam and water vapor from the interior of the modules. The plate load tests were discontinued after a sudden punching failure of the reg-set cap at 30,000 pounds (figures 89 and 90). Although thickness of the cap at the point of failure is uncertain, it was in excess of 12-inches, possibly as much as 20-inches thick. The failure was similar to that experienced in Test 1-4 NW, suggesting a failure of the supporting backfill material. Following this failure, one large slab 10-feet in width cracked and lifted up 3 inches over a 20-foot span along a 2-by-6 inch forming timber, allowing hot gases to escape before dropping back into position. An attempt to use the F-4 load cart failed when the pavement collapased beneath the load and allowed the aircraft tire to penetrate the pavement, stopping only when the frame of the load cart rested on the pavement (figure 91).

(2) Excavation into the pavement cap showed that the heat had destroyed all rigidity in the PVC, and allowed it to buckle under the load (figure 92).

(3) After a week the surface of the repair began to fail without loading, dramatically (figures 93 and 94). This failure was due to the reg-set cement and is covered in the next section.

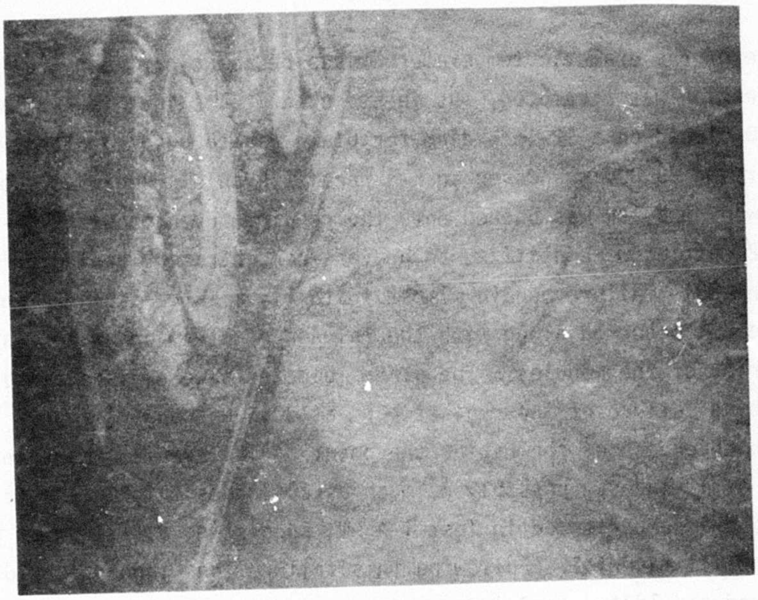


Figure 88. Test 2-1, AM-2 Matting Used to Support Load Trailer, Also Shown are Concentric Cracks

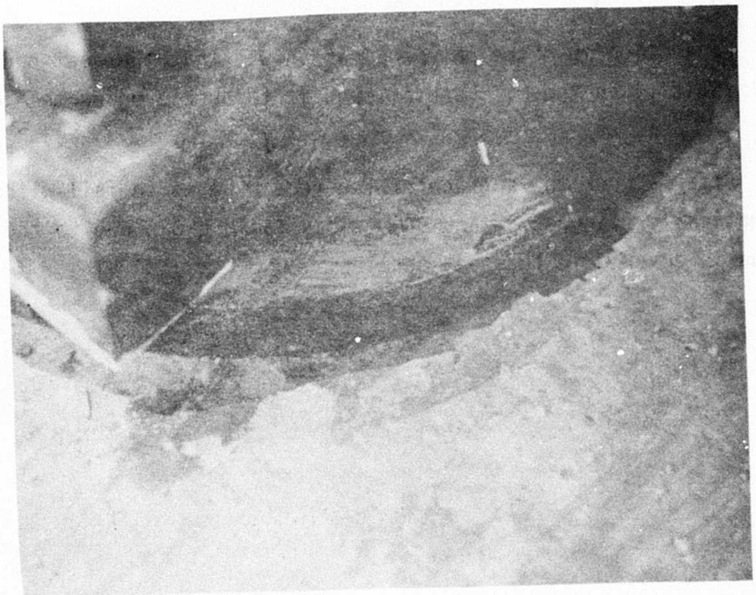


Figure 89. Test 2-1, Punching Failure of Reg-set Cap under Load Plate

Figure 90. Test 2-1, Punching Failure, Middle, and Concentric Crack, Lower

Figure 91. Test 2-1, Punching Failure under Load Cart Wheel

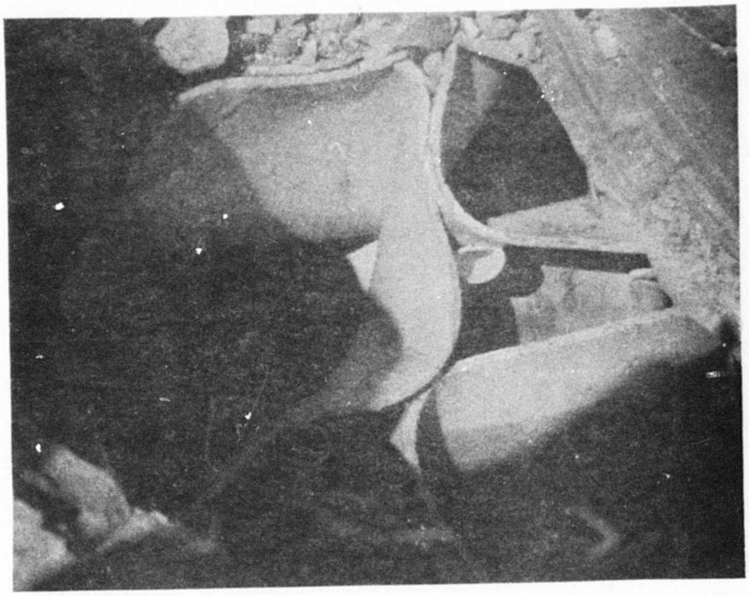


Figure 92. Test 2-1, Buckled PVC Module Elements Beneath Failure in Figure 91

Figure 93. Test 2-1, No Load Deterioration of Reg-set Surface

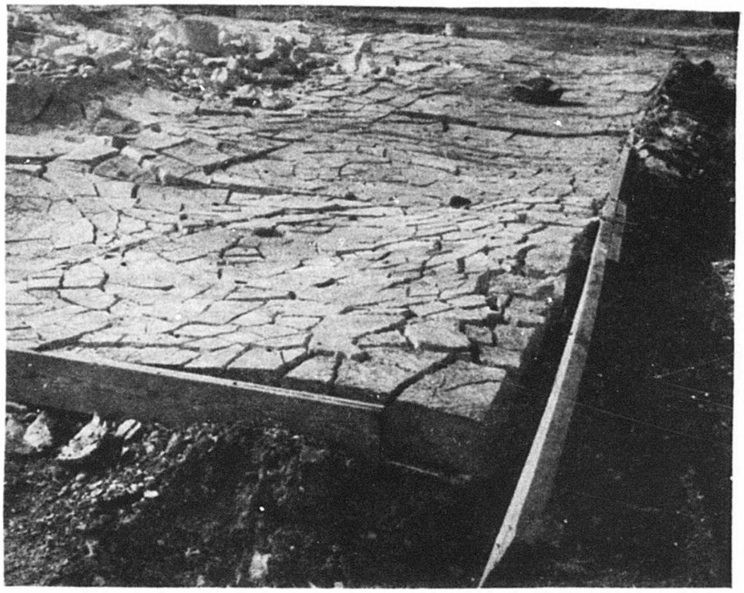


Figure 94. Test 2-1, Evidence of Expansion in Reg-set Surface

SECTION VIII

REGULATED-SET CEMENT

1. BACKGROUND

The use of regulated-set cement at the Tyndall BDR test site was designed to complement an effort being conducted for AFWL by the U.S. Army Corps of Engineers, Waterways Experiment Station (WES). This effort was initiated by the Aeronautical Systems Division (ASD), Wright-Patterson AFB, Ohio, and defined reg-set as an excellent candidate for use in BDR. This work culminated in WES Miscellaneous Paper C-72-15, Rapid Repair of Bomb-damaged Runways, Phase I, Preliminary Laboratory Investigation (ref. 11). Subsequent work in this area has been funded by AFWL and ASD. A report on all reg-set work is currently being prepared by WES (ref. 19).

2. MATERIAL DESCRIPTION

Regulated-set cement (reg-set) is a product patented by the Portland Cement Association (PCA), and is licensed for production by various manufacturers. Reg-set is a mixture of Portland cement and a halogenated calcium aluminate cement with an impressive early strength gain. In laboratory testing, reg-set slurry has gained up to 1,000 PSI in one hour. With the addition of additives and 10.5 percent Sodium Metasilicate, some reg-set has yielded up to 3,100 PSI compressive strength in 90 minutes (ref. 11). A standard specification for reg-set does not exist, and only the particular reg-set samples used in the laboratory testing can be said to definitely exhibit these qualities.

3. WES EFFORTS

Efforts at WES to date have included laboratory testing of reg-set and various exploratory equipment studies. Three crater repair tests were conducted and are described below.

a. First Reg-Set Testing at WES

(1) Procedure

The first WES test is described in a WES memorandum titled Bomb-damaged Runway Repair, Filling of a Simulated Crater (ref. 27). In this

test, conducted 27 march 1972, an excavated crater some 4 CY in volume was filled with 108 C.F. of reg-set foam and slurry, varying in density from 25.6 to 110.6 PCF. The gradation increased in density as the top of the crater was neared, representing the optimum use of reg-set. The total process took some 27 batches of reg-set mixed in a small concrete mixer. A 4-CY slurry cap was placed on the crater the following day.

(2) Problem Areas

This test highlighted several problem areas that needed additional emphasis in later tests. A total of 4300 pounds of reg-set was used in a 3-hour and 10-minute period. The reg-set cap placed the following day cracked badly. A heat build-up created a temperature of 208 degrees fahrenheit, although no detrimental effect on the curing process was noted. The foam backfill subside some 0.06-feet 3-hours after the completion of pouring.

b. WES Test No. 2

(1) Procedure

The second WES test was conducted on 30 and 31 May 1973 and consisted of the repair of two excavated craters. The craters had a top diameter of 30 feet and were 6 feet to 7 feet deep. It was envisioned that one crater would serve as a prototype test of the reg-set PVC module repair concept, utilizing four modules, foamed reg-set as a matrix for backfill and a reg-set cap. The second crater was to be filled exclusively with reg-set foam and have a reg-set cap.

(2) Repair of Crater No. 1

Module placement in the first crater was rapid. In fact, the supply of reg-set was too slow to produce accurate time results. An attempt was made to add debris to the reg-set foam, but the method of merely pushing debris down the side of the crater was inadequate (figure 95). No mixing of debris and foam was accomplished and the attempts were abandoned. Further complications arose when the reg-set placed in the crater cured too rapidly causing the formation of numerous cold joints and a highly irregular and unworkable surface. During the pumping of the cap, a hose connection broke due to an apparent pressure build-up in the system. This breakdown allowed reg-set slurry in the PVC pipe supply system to set up, stopping the operation until an alternate pipe system could be connected (figure 96).

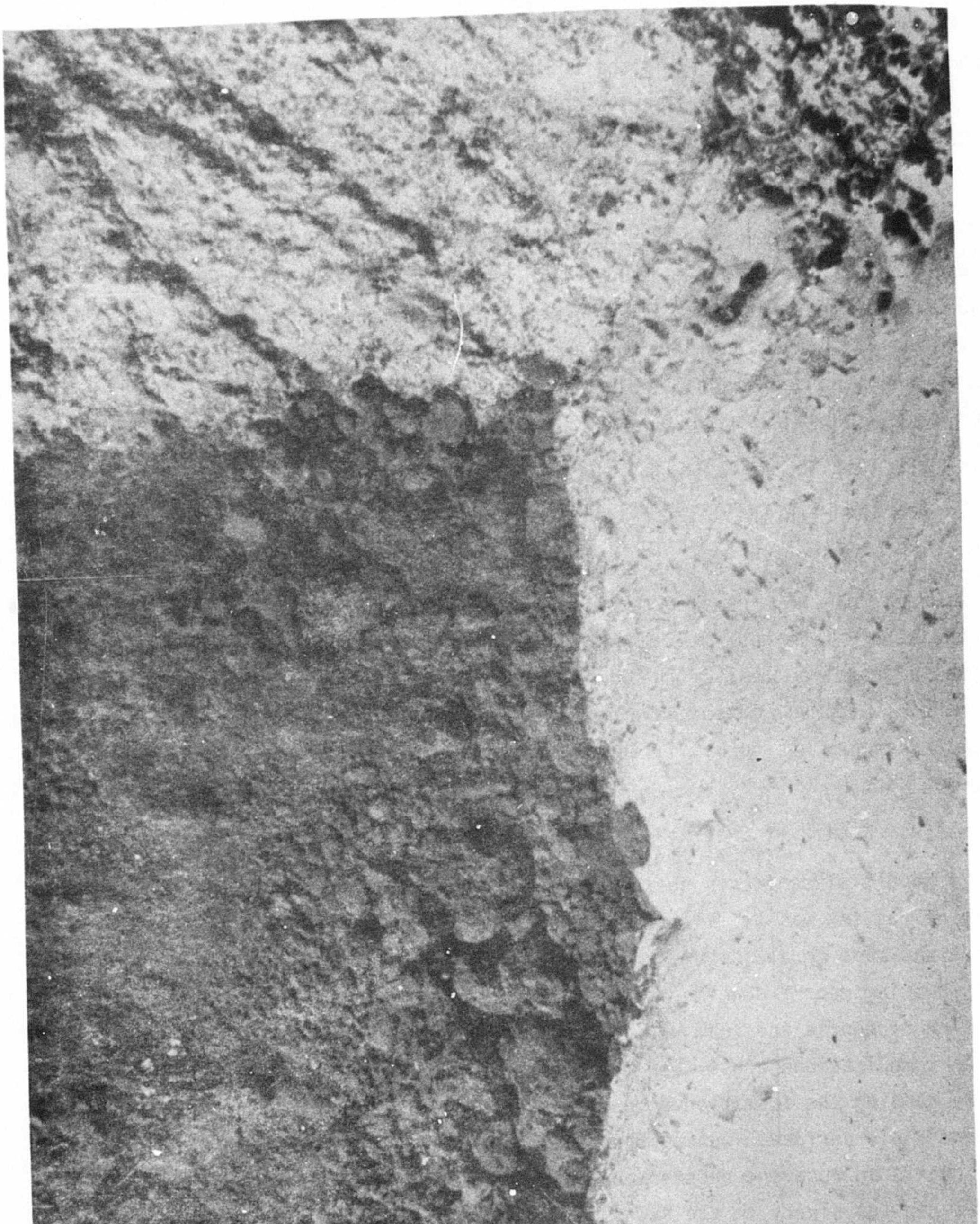


Figure 95. Mixing Problem, Debris with Reg-set Matrix Concept

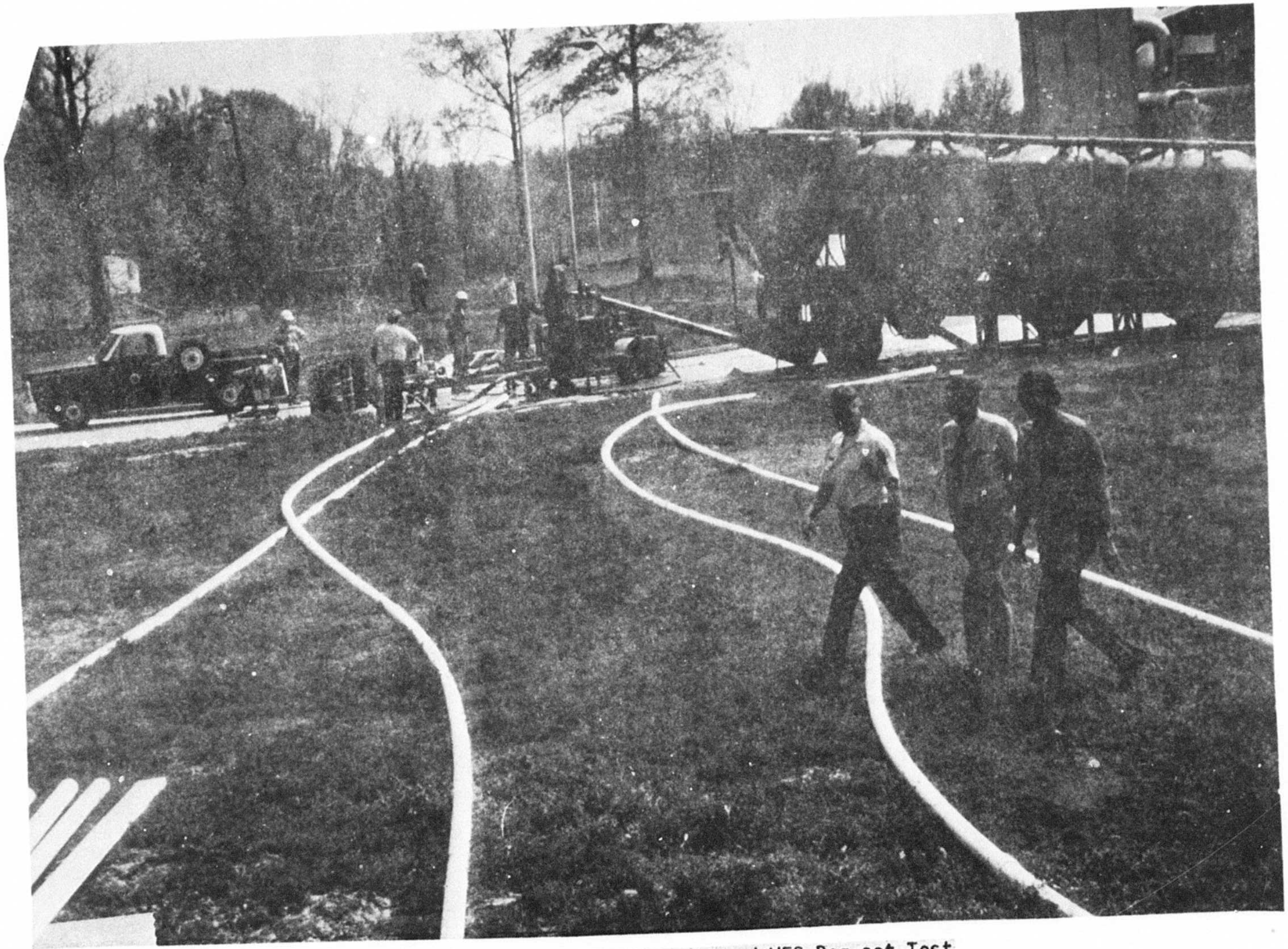


Figure 96. Supply Lines for Second WES Reg-set Test

An attempt was made to drive a front loader on to the repair following the test, but extensive cracking occurred and the machine was removed. To determine the cause of the cracking, the unfinished cap was excavated, exposing the PVC modules. A system of cold joints as described was observed. This excavation also vented the gases within air spaces in the modules, and hot water vapor continued to flow out of this opening throughout the afternoon and during the following day. It was theorized that the water was coming from throughout the cellular foam structure, indicating a very open structure. It also indicated excessive losses of water from the reg-set foam mixture, thus not allowing a proper curing process to occur.

(3) Repair of Crater No. 2

The second crater in the second WES test was filled with foam and topped as nearly as possible with a reg-set slurry. Again problems realized in the previous tests arose. The set time of the reg-set was unpredictable and cold joints were formed in the foam and in the slurry. Because of the high temperature of the slurry as it arrived and the heat released by the curing reg-set mass upon which the slurry was placed, the reg-set set up in thin pancake like sheets (figure 97). An apparent build up of curing reg-set in the system created back pressure on the flexible connector at the pump and caused a line failure. This in turn allowed the reg-set slurry stranded in the supply line to set up. An alternate PVC pipe supply line (3 inches) was used, but it too failed and the project was abandoned before it was completed. WES personnel stated that the slab was finished the following morning with no further problems.

(4) Load and Material Testing

No load testing was accomplished in the above tests. A thermocouple was placed in the second crater to monitor the heat generated. The peak temperature was in excess of 200 degrees Fahrenheit. Cylinders cast during this test showed a strength of 880 PSI in one hour. This low value was apparently due to a water/cement ratio problem.

c. WES Test No. 3

(1) Procedure

The third WES test was run at the request of AFWL to solve several of the problems noted in the first two WES tests. These problems are detailed

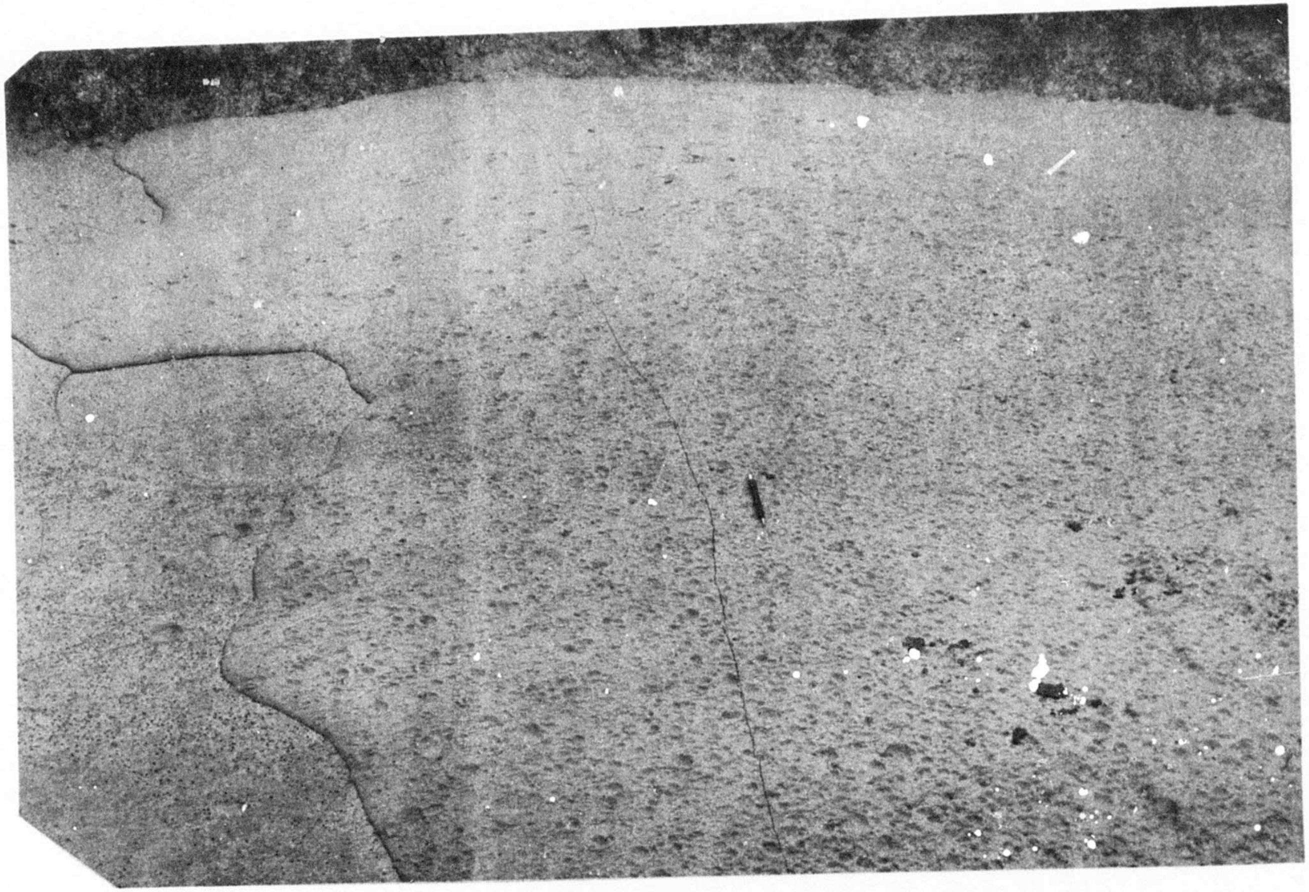


Figure 97. Cold Joints Resulting from Flat Sheetlike Curing of Reg-set

later, but involved placement of reg-set, screeding, logistics, retardation, and foam to slurry transition.

(2) Repair

Two concrete slabs, reinforced with welded wire mesh (figure 98) were pumped to test the items listed above. A major problem developed in attempting to hold the retarded reg-set in the forms long enough for it to set up. It was determined that the forms would be indispensable if an acceptable surface were to be put on the reg-set cap. The retardant system seemed to be improved over the method of adding the citric acid crystals by hand as used in the second test. An injector system was used allowing a controllable amount of citric acid solution to be placed in the system if a steady input water pressure were maintained. Problems with the pump equipment and the mechanical supply of reg-set terminated the test, with the reg-set actually setting up in the mixer (figure 99).

d. WES Equipment Usage

Equipment used for the tests as WES led up to the choice of items for use at Tyndall. For the first WES test, no more than a motorized concrete mixer was required, though a multitude of batches were required. Supply of reg-set was done by hand breaking the sacks into the mixer. The second test used a Strong gypsum pump. This machine, model G-2, uses a paddle wheel rotating in a tub to mix the cement and water. When mixed, the slurry is pumped through a supply hose to the site. At WES, 3" PVC was used as supply line, with specifications of PVC 1220, Schedule 40, 260 PSI as outlined by ASTM. The Strong pump was potentially capable of mixing and pumping a low density foam (50-75 PCF) at a rate of 60 CY per hours. This required some 725 pounds of dry cement to be delivered to the pump each minute. To keep up with this demand, adequate cement storage and adequate cement supply to the pump at all times were required. To fulfill these requirements, large mobile pneumatic storage bins were rented (figure 100).

Unlike the first WES test where a foaming agent was prefoamed and then blended in the mixer with the slurry, a special foam pump was used which added and mixed the foam-slurry product in the supply line. This worked exceptionally well.

Figure 98. Welded Wire Mesh (WWM) Reinforced Reg-set Slab, Third WES Test

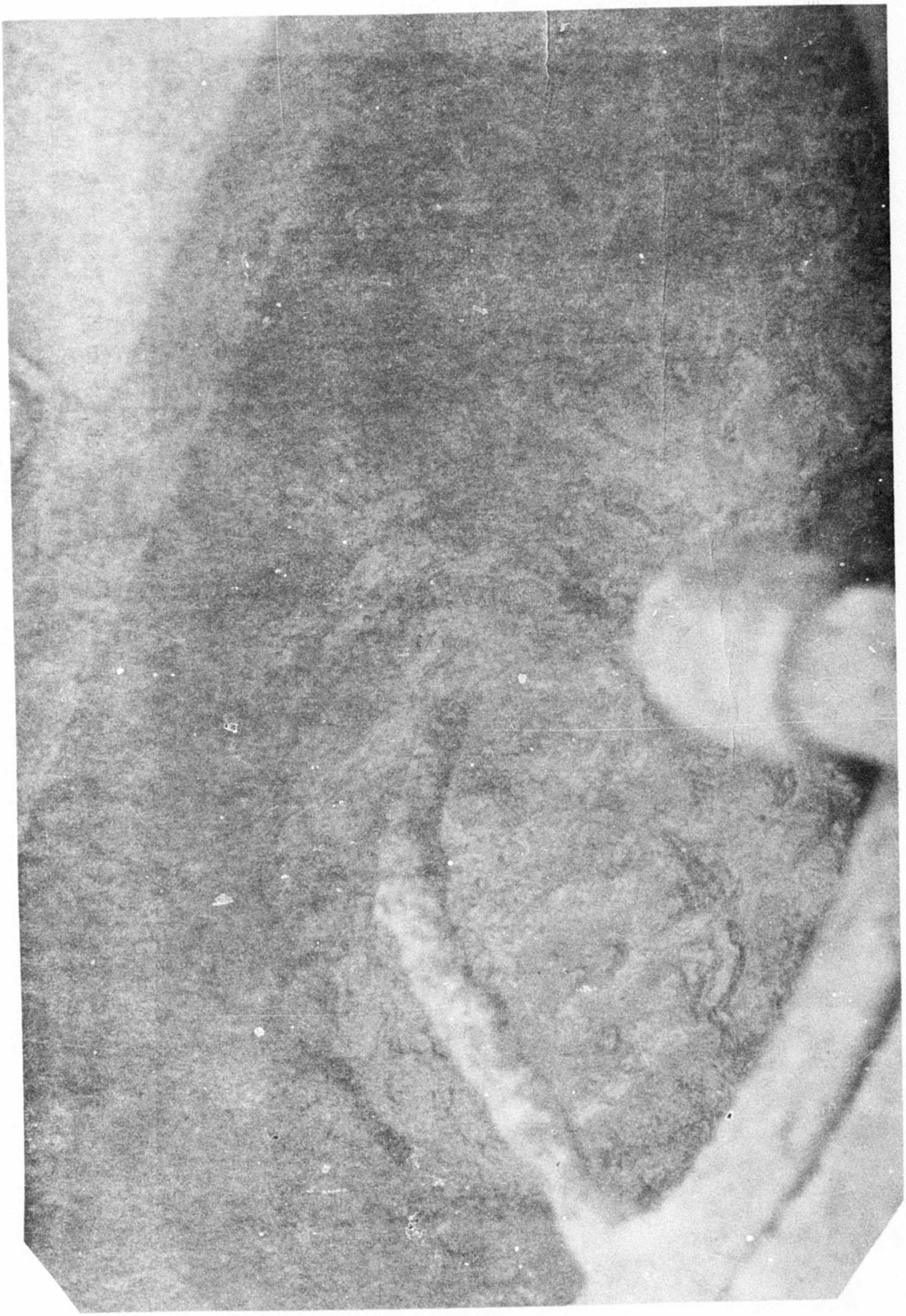


Figure 99. Reg-set Slurry Set up in G-2 Mixer Tub

Figure 100. Mobile Pneumatic Storage Bin, Second WES Test

The third WES test used equipment similar to the second WES test, with the exception of the storage of dry reg-set cement. Large rubber containers (figure 101 and 102) capable of holding up to 6,000 pounds each were emptied directly into an open hopper, from which a feed auger was fed by gravity. Removing the reg-set from the bags proved to be too slow a process, and the dry cement feed fell behind, causing at least one system failure.

In general, the WES tests provided background for the full scale tests at Tyndall. Each test showed an improvement in the capability of the reg-set system to be tested full scale. However, serious reservations were still held prior to the beginning of the Tyndall tests.

e. Problems Identified at WES

The problems which were identified at WES are detailed below:

(1) Equipment

A definite problem of equipment existed. The nature of reg-set is such that any delay in delivery of the material to the repair area can result in the reg-set becoming set up in the equipment. This delay can be caused by faulty equipment, or delay in delivery of water or dry cement to the mixing machine. If an interruption does occur, some method of back flushing and cleaning the equipment instantaneously must be devised. Additionally, the time constraints of repair required equipment with a much larger output than is currently available. Although two pumps were utilized for these tests, excessive time was required for the repair.

(2) Reg-set Set Time

A lack of control over the set time of reg-set slurry existed. The speed at which reg-set sets up is dependent upon the specific cement used, the amount of retardant (citric acid) in the slurry or foam and the temperature of the slurry or foam. The temperature of the slurry is dependent upon the ambient temperature, the temperature of the supply water and cement, and the friction in the supply line, a function of line length, line roughness, etc. In addition, reg-set delivered to the repair after previously placed material has started to hydrate will be subjected to still higher temperatures. Once the set time is determined, a system of retardant metering based on the material used and temperature inputs would be required to maintain that time. The ability to vary set time is based on the assumption

that set time will not interfere with strength gain.

(3) Foam Debris Mixing

A problem with the introduction of debris into the reg-set foam existed. The debris must be added before initial set up begins, prefereably by raining the debris into the reg-set foam matrix to insure complete submersion.

(4) Screeding

In order to construct a surface acceptable for aircraft, some method of rapid screeding before set up is required.

Figure 101. Rubber Field Containers Stored for Use in Tyndall Test 2-1

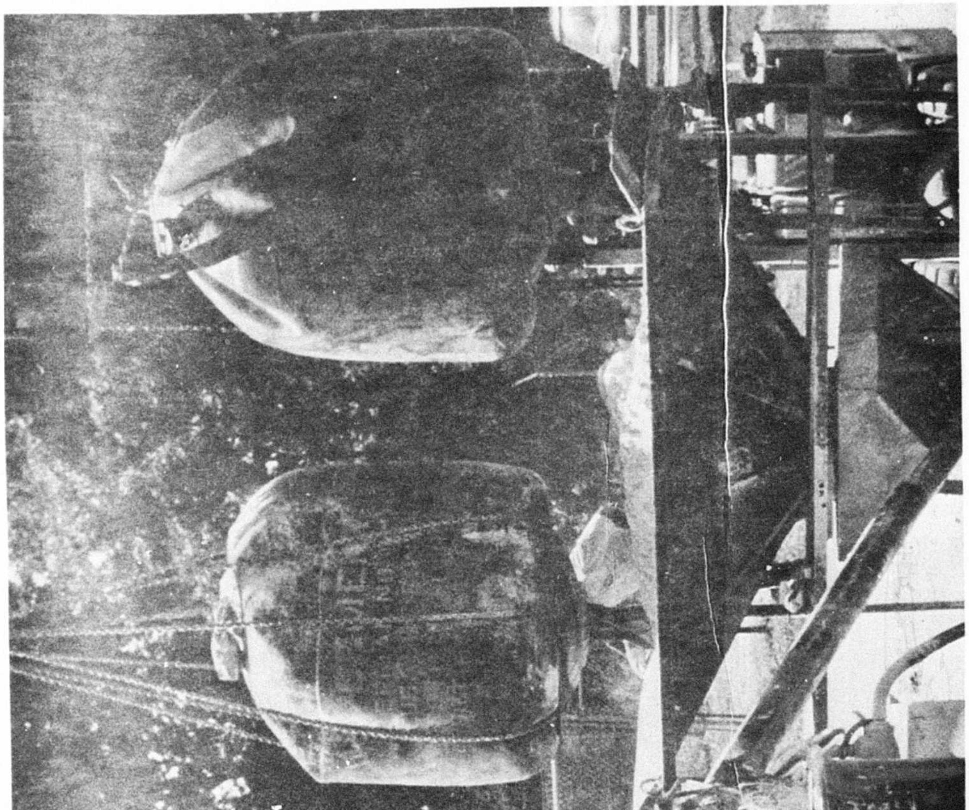


Figure 102. Rubber Field Containers Being Used in Third WES Test

4. TYNDALL TESTS

a. Overview

Following the tests at WES, tests were conducted at Tyndall AFB for two primary purposes: first, to iron out the problems encountered at WES; second, to test full scale the various reg-set usage techniques. Tests included the pouring of two 15-foot square test pads and the conduct of Tests 1-4, 2-1, and 2-4. Tests numbered 2-2 and 2-3 were also scheduled. Test 2-2 was to test a reg-set cap over a uniformly graded aggregate backfill and 2-3 was to test the use of reg-set foam as a matrix for debris with a reg-set cap. Both Tests 2-2 and 2-3 were cancelled as a result of the dismal performance of reg-set during Test 1-4 and 2-1.

b. Pouring the Test Pads

(1) Objectives

The objectives for pumping two 15-foot x 15-foot test pads to test the screeding system and alter it as necessary, to test two Strong G-3 pumps obtained on lease from the Strong Manufacturing Company and to train AFCEC personnel who would actually be performing all reg-set tests at Tyndall.

(2) Screeding System

The screeding system devised consisted of an attempt to break the surface into small enough areas to provide for screeding before initial set and to allow close access to the area bing screeded. The 15-foot x 15-foot size selected proved to be too large for the use of standard concrete finishing equipment. It was determined that future tests would require the use of 10-foot widths with a screed board to accurately control the surface finish.

(3) Equipment

The Strong G-3 pump being tested is shown in figures 103 and 104. It was similar in most respects to that used at WES. A hydraulic transmission was added to solve certain mechanical problems and the pump model changed from G-2 to G-3 as a result. The two pumps to be tested were capable of pumping up to 60 CY per hour. Specifications for the G-1 and G-2 pumps are given in appendix VIII. In addition to testing of the pumps, various

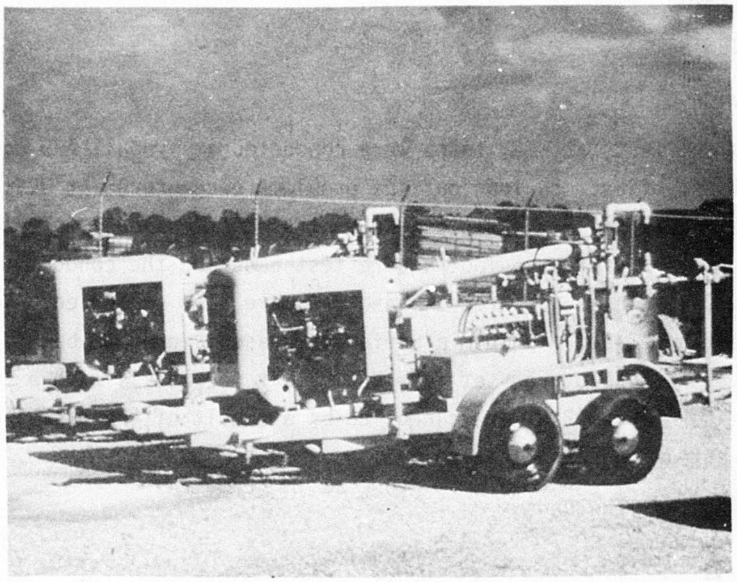


Figure 103. Overall View of Strong G-3 Pump

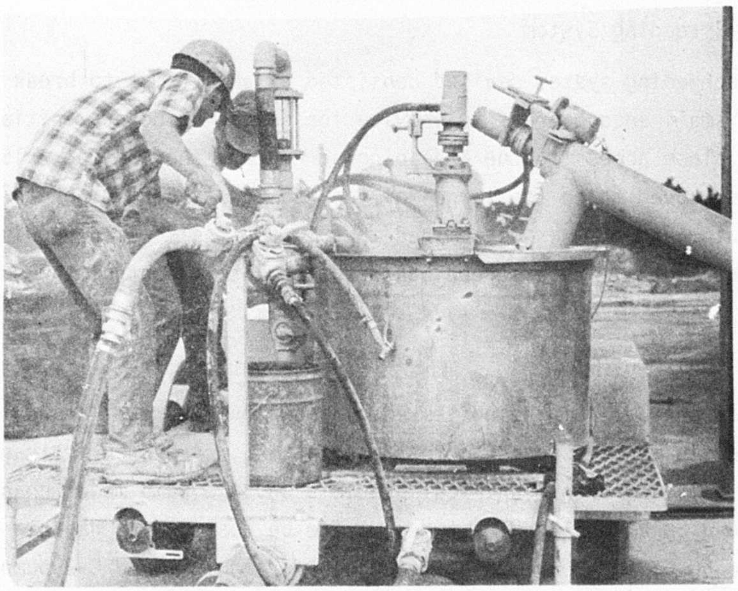


Figure 104. View of Mixing Tub and Reg-set Supply Line, Strong G-3 Pump

other components of the system were trail run. These included the Waukesha model C0620-8 foam generator, specifications for which are contained in appendix IX, and the feeding of the dry cement feed augers by gravity from bulk rubber field containers (figure 105). The sizing of the pipe and flexible hose was tested, as were retardant injector systems based on a venturi tube for introduction of the citric acid retardant into the mix water. Portions of this equipment were used in earlier WES tests.

With the exception of the feed system, the equipment tested was acceptable.

c. Test 1-4

(1) Procedures

Test 1-4 explored the usefulness of reg-set cement for craters made by small penetraing weapons. Three different methods of repair with reg-set were used. Test 1-4 SW used a debris backfill similar to Tests 1-1 and 1-4 NE, with a reg-set cap. Test 1-4 SE used the concept of infiltrating reg-set slurry into prepositioned uniformly graded aggregate. The full repair process for Tests 1-4 NE, NW, SW and SE is covered in section VI. Reg-set details only are covered below.

(2) Test 1-4 SW

(a) Test of Techniques

Test 1-4 SW was the first of the actual crater repairs run with reg-set. The debris backfill was compacted with a vibratory roller, then formwork was set to divide the repair area into two sections 10 feet or less in width, figure 106. This 10-foot width proved to be suitable for hand screeding. Equipment problems caused a shut down before the first lane directly over the center of the repair could be completed. The following day the second section was poured and the first completed. Because of the cold joint that would exist over the debris, the plate load was taken on the second section which was mainly over the previously undistrubed base course. The load test time penetration curve is given in figure 71, section VI. A total of 399 square feet of reg-set was poured in the repair, amounting to some 15 tons of reg-set cement and 1450 gallons of water. The cap placing process was considered a procedural success, allowing planning for Test 2-1 to continue.

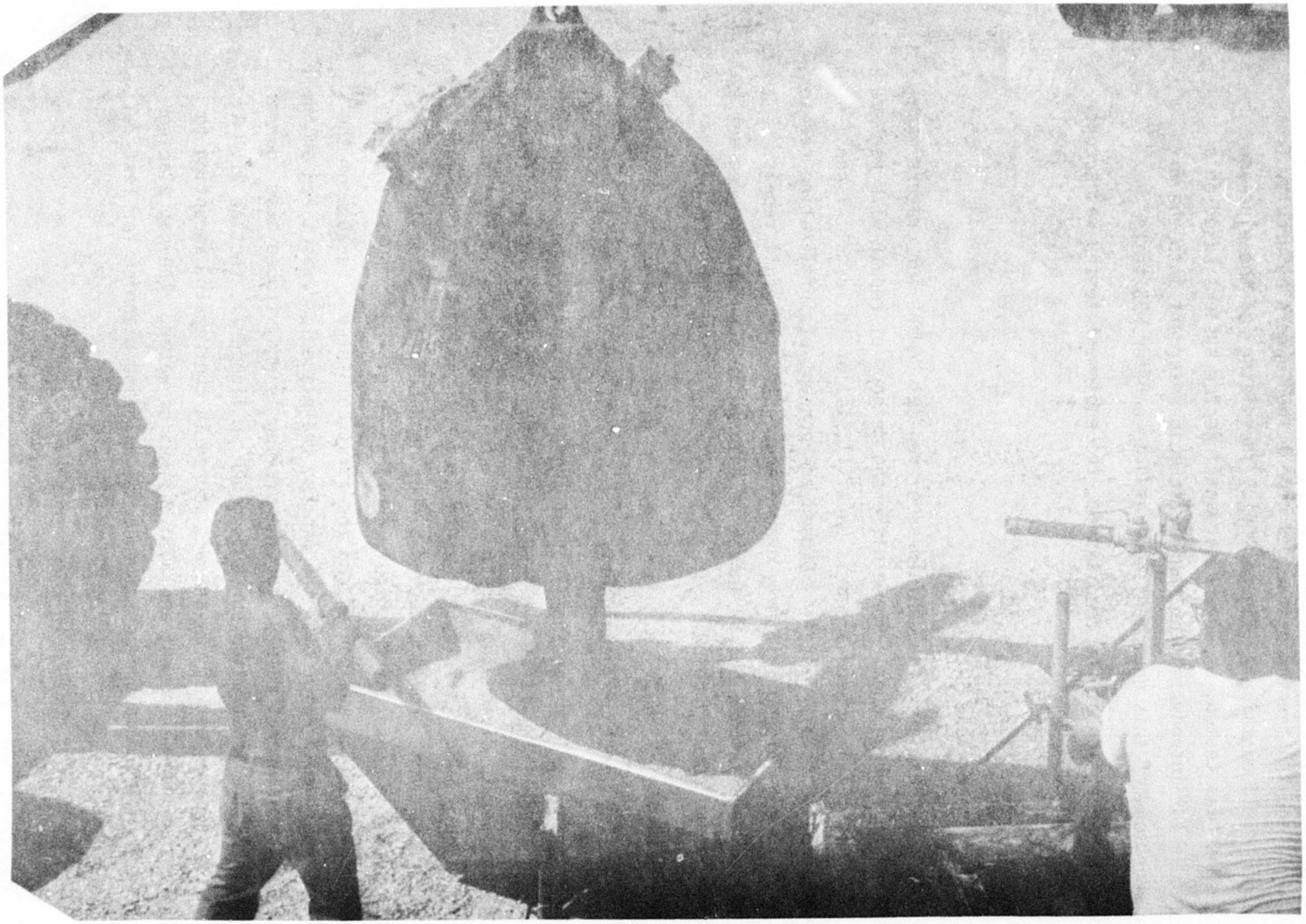


Figure 105. Feeding Bulk G-3 Hopper From Rubber Field Container

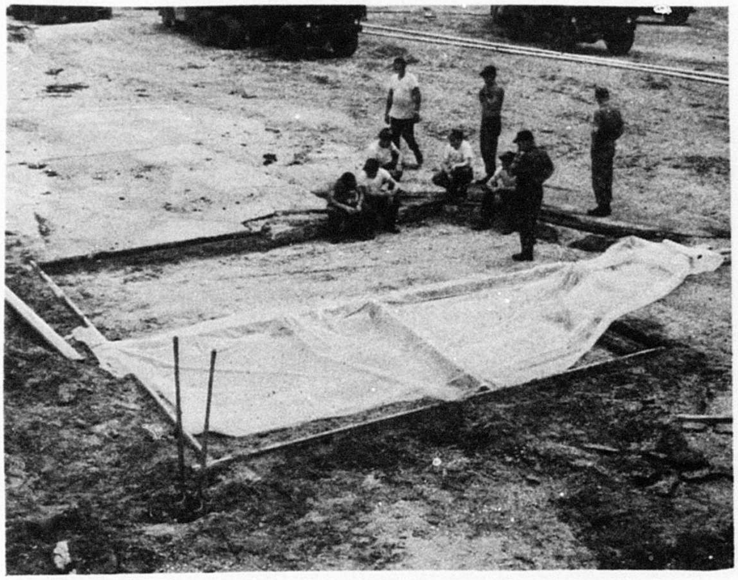


Figure 106. Screeding Formwork, Test 1-4 SW

b. Equipment

Reg-set equipment used on this test was similar to that used in earlier pad tests at Tyndall. A large transit mix storage silo was used as open bulk storage. It was filled prior to testing by crane and from rubber field containers, as used at WES (figure 107). During testing, it was further filled from pneumatic bulk trucks. The silo had been modified to have three chutes to deliver cement by gravity to the hoppers of each of the three pumps to be used in Test 2-1. Several factors worked against this equipment. By being open, atmospheric moisture was allowed into the hygroscopic reg-set cement, causing small lumps of hardened cement to form. These lumps bound up the pump feed augers several times. Another problem was arching of the cement in the bin at the high feed rates that were required to keep the separate machine hoppers full. Some 1920 pounds of dry cement are required for a yard of slurry at a 0.55 water/cement ratio. This rate was impossible to maintain, and alternative methods of on site storage had to be sought.

Figure 107. Feeding of Open Bulk Ready Mix Hopper from Rubber Field Containers

(3) Test 1-4 NW

(a) Test of Repair Techniques

Test 1-4 NW was successfully run, with a reg-set foam backfill and reg-set cap. In this application, a cellular foam with an approximate density of 50 PCF was made by introducing a protein base organic foam into a regulated-set cement slurry of 110 PCF density. This foam was pumped into the crater (figure 108) to a level 1-foot below the finished surface. At this point, the foam was deleted and a pavement cap of reg-set cement slurry was pumped and finished (figure 109).

(b) Load Testing

Loading of the slab was accomplished about 1 hour and 30 minutes after the completion of pouring. The repair failed under a 12-inch diameter load plate. The time penetration curve is shown in figure 71. Figure 110 of the failed surface shows that a punching shear of the cap was caused by failure of the underlying material, i.e., the reg-set foam. One possible contributing factor was the floating of foamed cement in the neat

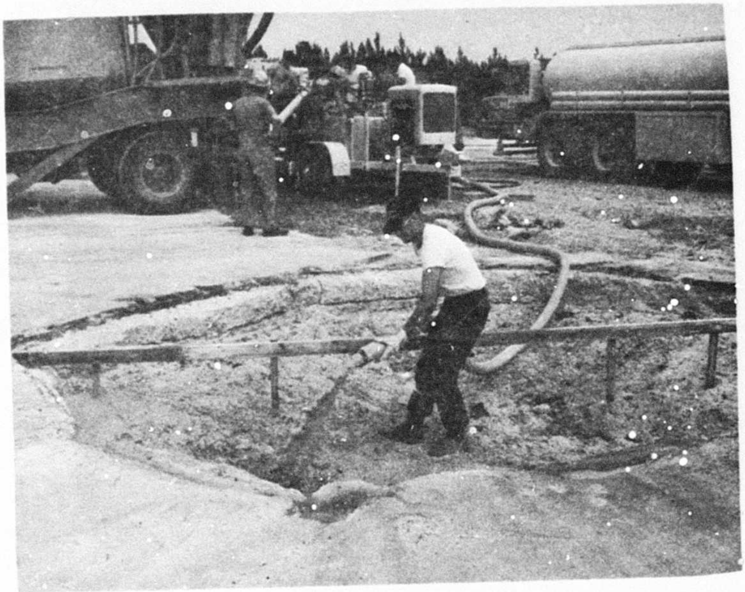


Figure 108. Reg-set Foam Being Pumped into Crater 1-4 NW

Figure 109. Reg-set Slurry Cap being Pumped on Crater 1-4 NW

Figure 110. Punching Failure on Reg-set Cap Test 1-4 NW

slurry (figure 111) yielding a possible weakend lower 2 inches of the 12-inch slurry cap. Excavation of the cap, figure 110, showed the failure plane to be very nearly at 45 degrees to vertical, in agreement with Mohr Circle theory defining the plane along which maximum shear occurs. It was noted that the surface temperature of Test 1-4 NW was much higher than the surface temperature of other 1-4 series tests.

(c) Equipment

Test 1-4 NW was the first to use a new cement storage and delivery system leased for the large quantity requirements of Test 2-1. Rather than the open storage and gravity feed of Test 1-4 SW, three mobile bulk storage units, identical to the one used on the second test at WES, were leased. These units (figure 100) held up to 1200 CF of cement each and could feed the hoppers of the Strong G-3 pumps at any rate desired with no dependence on gravity. These units worked exceptionally well for the small 1-4 NW reg-set requirement of only 15 tons. As in Test 1-4 SW, water requirements were met by trucking the required 1980 gallons to the site in a standard 5,000-gallon semi-trailer.

Figure 111. Chunks of Foam Reg-set Floating in Reg-set Slurry Cap, Test 1-4 NW

(d) Specific Problems

Some problems were experienced in screeding this repair (figure 112) and it was realized that a carefully controlled and prefabricated form system would be essential for further work with reg-set.

(4) Test 1-4 SE

(a) Test of Repair Technique

The final reg-set repair in Test 1-4 infiltrated reg-set slurry into a prepositioned 3/4 to 1-½ inch uniformly graded aggregate. This material was thoroughly washed after placement, and a regulated-set cement slurry was flooded on the surface (figure 113). The cement infiltrated the material to the depth of the uniform aggregate. The resulting slurry surface was alternately screeded with a 10-foot board and with a 3/4 inch vinyl tube (figure 114). The surface was cured by flooding with water.

(b) Load and Material Testing

Testing of this slab resulted in excellent findings, with the load of 50,000 pounds on a 12-inch diameter plate easily sustained (figure 71). The ability of this material to carry a load of this nature prompted

the design of Test 2-4 to be covered later.

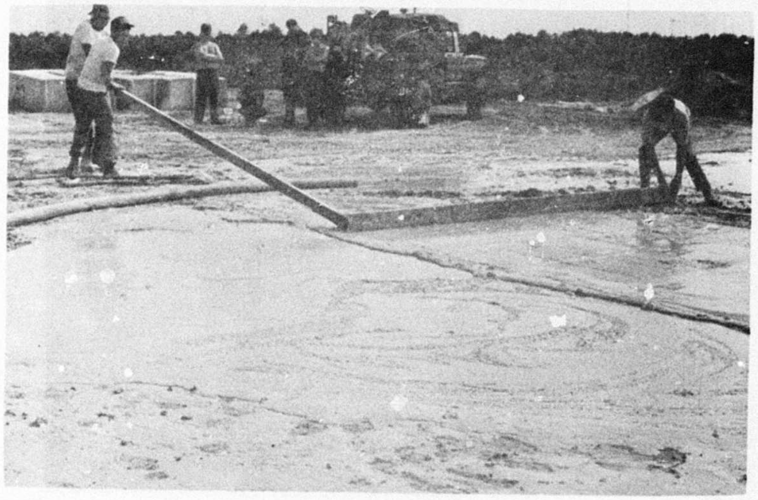


Figure 112. Screeding Reg-set Cap for Test 1-4 NW

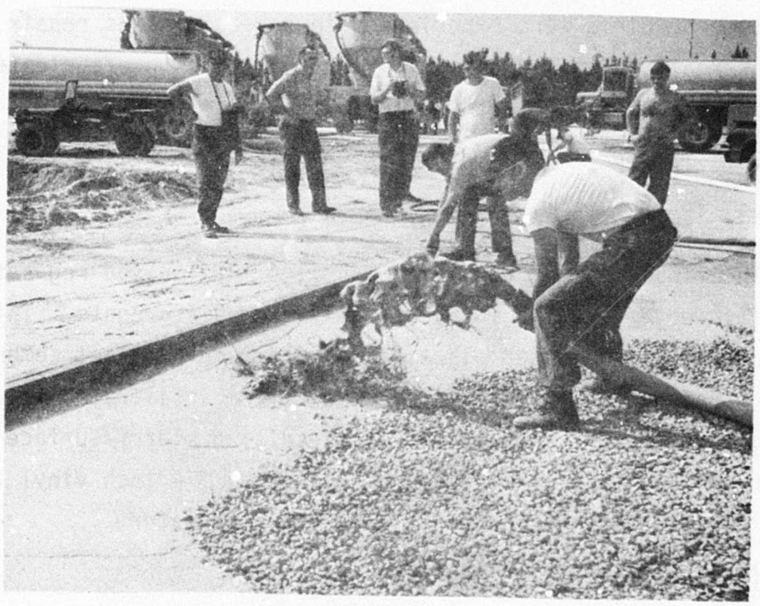


Figure 113. Infiltrating Slurry into Prepositioned Aggregate, Test 1-4 SE

Figure 114. Screeding Slurry Infiltrated Cap with 3/4" Vinyl Tube

the design of Test 2-4 to be covered later.

Core drills were taken to determine if adequate penetration of the aggregate was made by the reg-set slurry (figures 115 and 116). The short cylinder was attributed to the presence of sand contamination in the aggregate. This contamination was known before pumping, and an unsuccessful attempt had been made to wash it out with water under high pressure. However, it did demonstrate that sand makes an excellent slurry cutoff for controlling the depth of penetration.

(c) Equipment

The equipment used for this test was the same as that used for Test 1-4 NW.

d. Test 2-1

Test 2-1 was covered in section VII devoted to the overall test, with emphasis on the use of PVC modules. This section deals only with the use of the reg-set cement.

(1) Repair Technique

The technique used for reg-set placement was very similar to that used for Test 1-4 NW. The quantity used was the largest amount of reg-set

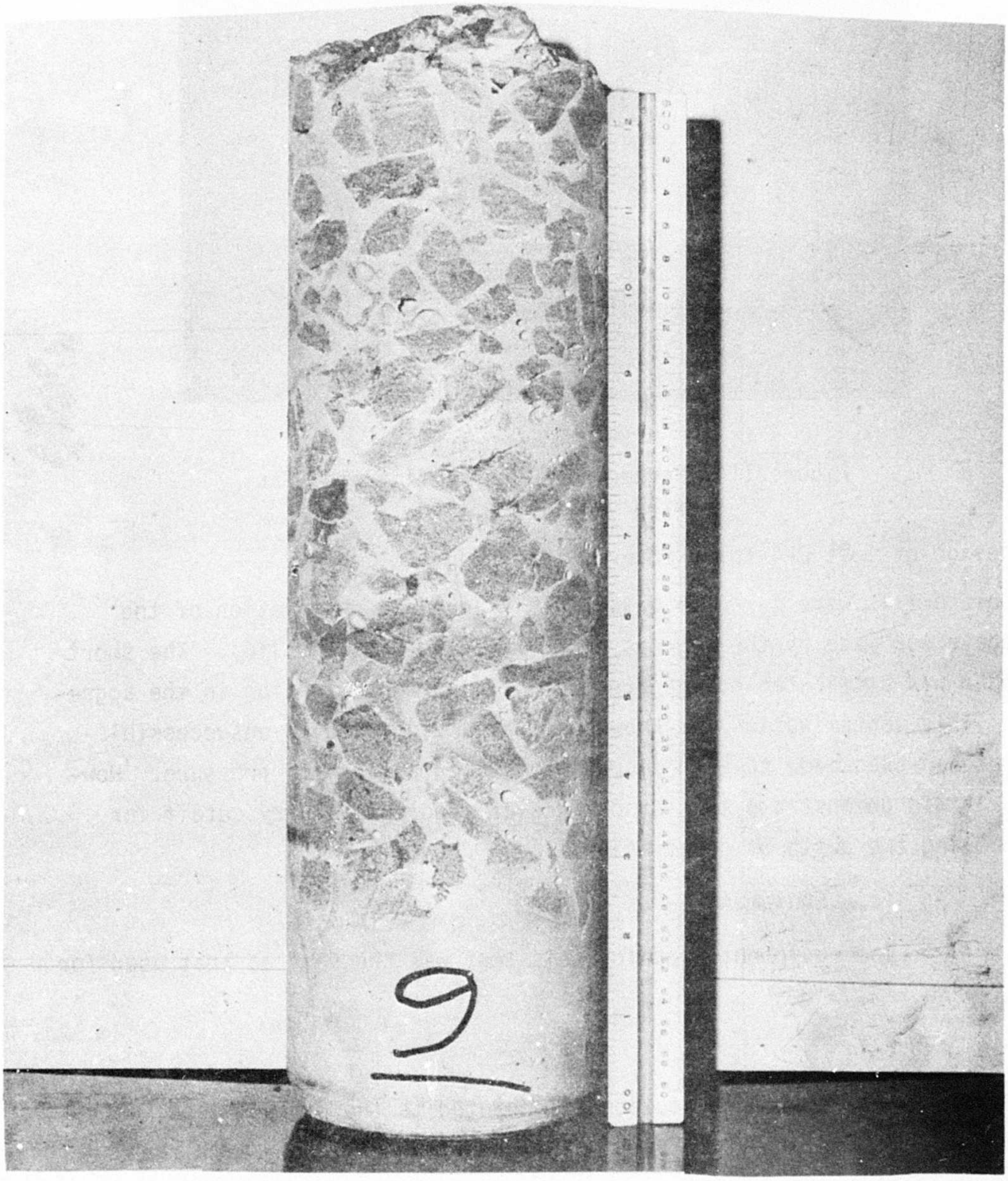


Figure 115. Core Sample of Infiltrated Aggregate Cap, Test 1-4 SE

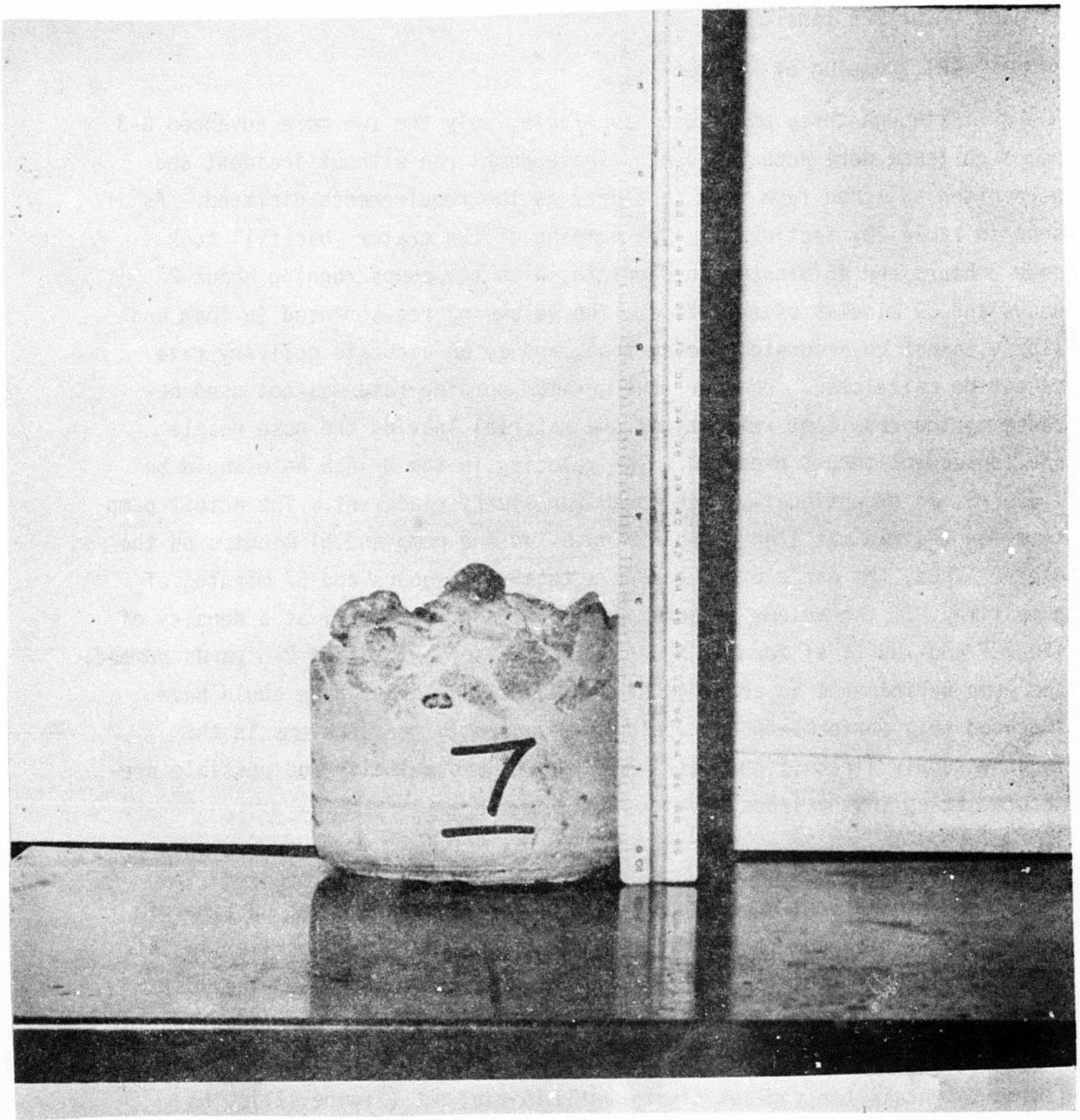


Figure 116. Core Sample Illustrating Slurry Cut Off by Fines

pumped on the surface in any application in the world to date. WES is believed to have pumped much larger quantities in underground applications at the Nevada Test Site. All three of the approximately 1230 CF capacity mobile field bins were exhausted, as were two semi-trailer loads with a volume in excess of 400 CF each. The total volume of dry reg-set cement was in excess of 4500 CF or 225 tons.

(2) Pumping of Reg-set

Although three pumps were available, only the two more advanced G-3 pumps on lease were actually used. These pumps ran without incident and were often switched from foam to slurry as the requirements dictated. As seen in table 20, section VII, the pumping of the crater backfill took some 2 hours and 46 minutes to complete, with the pumps running about 2 hours and 29 minutes of this time. The volume of reg-set used in foam and slurry cannot be accurately determined, and so an accurate delivery rate cannot be calculated. However, the maximum pumping rate was not used because of the resultant velocity of the material leaving the hose nozzle and consequent thrust produced. The velocity in the 3-inch hose would be 7.45 FPS, an exceptionally high speed for slurry placement. The actual pump time for the cap was 1 hour and 8 minutes on one pump and 51 minutes on the other. Thus, the whole project took a total of 6 hours and 57 minutes of pump time. If the volume is assumed to be 175 CY of slurry at a density of 110 PCF and 100 CY of foam at a den of 50 PCF, or a total of 275 yards pumped, the pump performance is about 40 CY per hour. A larger hose could have improved this performance but would have caused larger problems in the lengthy supply lines (figure 117) due to reduced velocity and possible premature set-up in the lines.

(3) Screeding

Screeding went exceptionally well, even though the set up time of the reg-set varied due to the temperature factors mentioned earlier in this section. Figures 118, 119 and 120 show the screeding process. The most serious problems seemed to be the exceptionally fatiguing work involved in both hose handling and screeding and the failure of the polyethylene form lining to retain the reg-set slurry until initial set (figure 121). No serious screeding problems arose until the citric acid content was decreased, and a more rapid set time caught the screed crews off guard. In general,

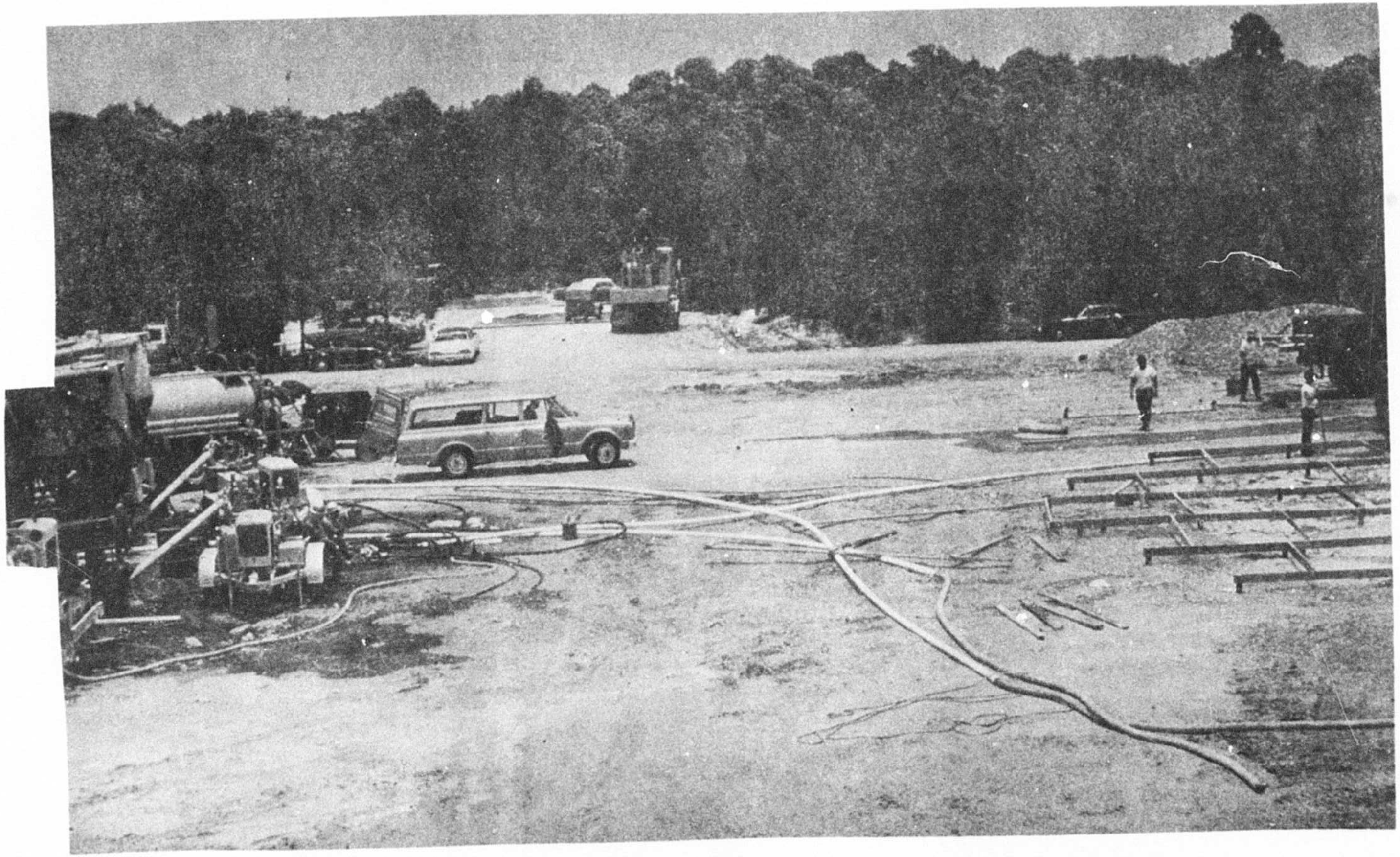


Figure 117. Lengthy Supply Lines for Test 2-1

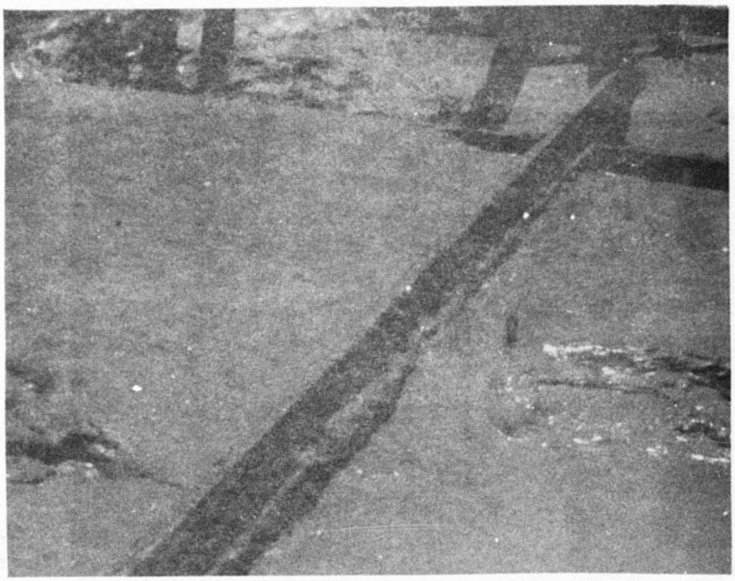


Figure 118. Initial Screeding of Reg-set Cap, Test 2-1

Figure 119. Screed Team Working Center Lane, Test 2-1

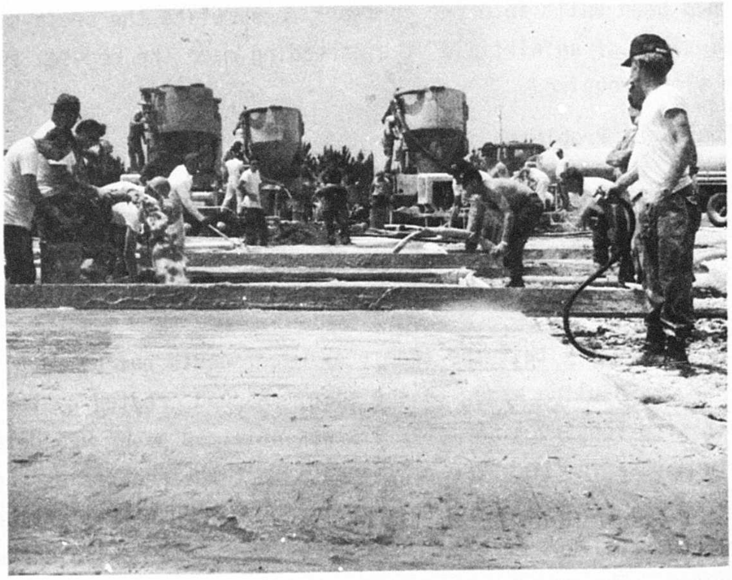


Figure 120. Final Screed Surface, Test 2-1, with Mobile Bins in the Background

Figure 121. Reg-set Running Beneath Polyethylene Form Liner and Out of Formwork, Test 2-1

the surface of the patch was suitable for aircraft. Even though a pronounced slope had been built into the formwork to simulate the cross-slope and logitudinal slope of an airfield, the screeding made the reg-set surface conform to the slope required.

(4) Equipment Problems

One pump was cut off early when the necessary handling of the PVC supply lines resulted in a joint failure. The pump was restarted but shut down again when one of the two 5,000-gallon tank trucks being used to supply water ran dry.

It was determined early that the supply of water could not be supplied fast enough by trucks hauling water to the site. A pond created by the borrow pit for the test site construction materials was utilized after WES determined that the organic matter in the water would not affect the reg-set strength properties. Water was pumped from this pond into the supply trailers and then pumped from the trailers at higher pressures through a manifold system to the slurry pumps. The supply water pump could not keep up with the demand and the semi-trailers were eventually emptied. It is estimated that approximately 30,000-gallons of water were used in the test.

(5) Reg-set Curing

Curing of the concrete was accomplished by inundation or flooding as soon as the shine was gone from the surface. Curing continued for about 2 hours after the completion of placement.

(6) Load and Material Testing

Loading was accomplished as outlined in section VII.

(a) Site Deterioration

The test site was revisited two months after the test. The surfaces of tests repairs 1-4 NW and 2-1 were made unusable by extensive surface cracking from shrinkage (figures 93 and 94, section VII). In addition, evidence of wide spread expansion was present, especially over the foam subgrade area (figure 122). Test 1-4 SW and 1-4 SE were not observed to have failed in a similar manner. It was at first felt that the water used in Test 2-1 could be at fault, however, treated water of high quality had been trucked to the site for Test 1-4 NW, eliminating this possibility.

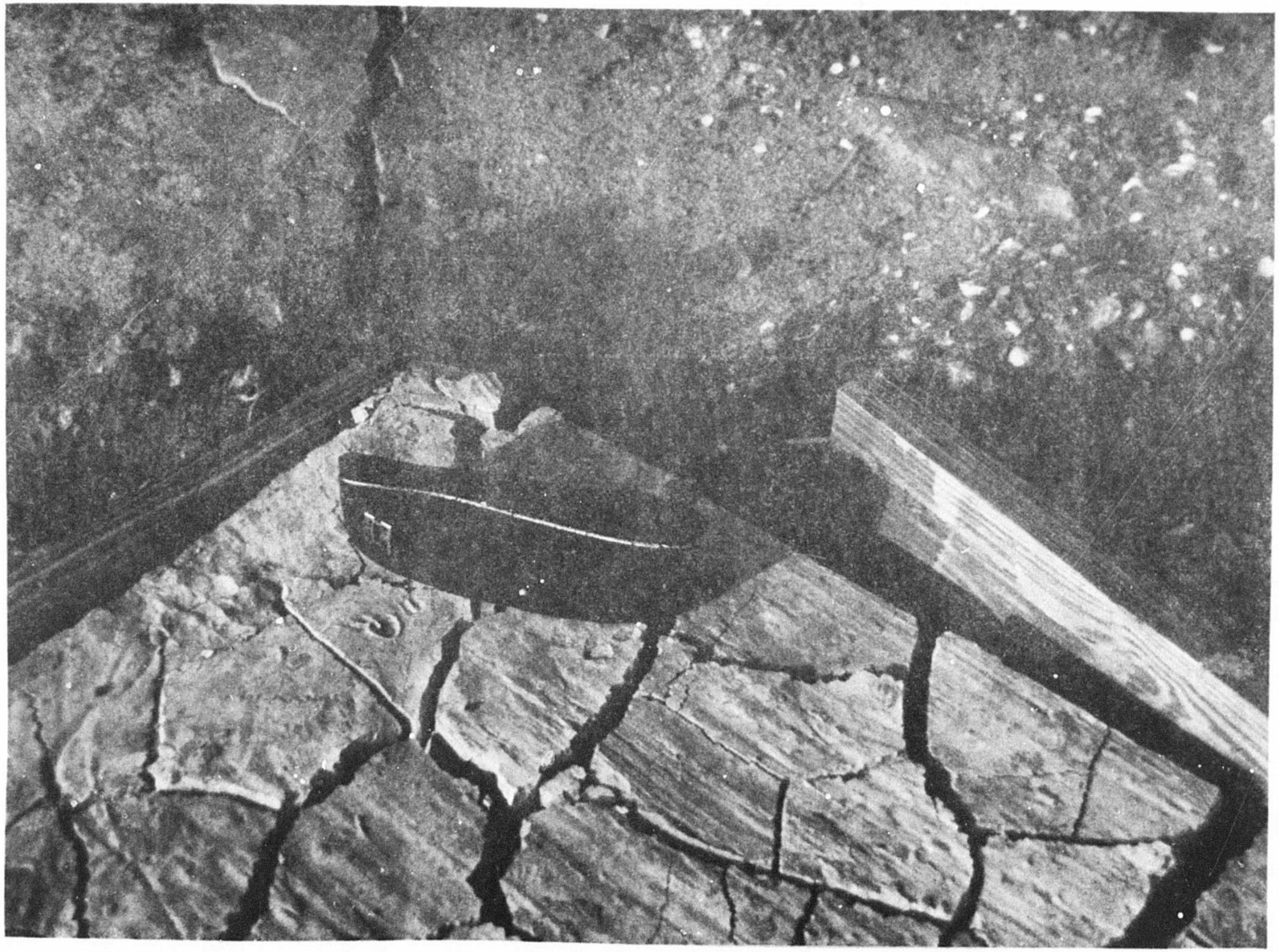


Figure 122. Evidence of Extreme Expansion, Deteriorated Cap, Test 2-1

(b) Core Sample Testing

Concrete cores were taken from the test site and tested for compression and flexure on 17 July 1973, some 18 days after the test. Strengths recorded, table 22, are low when compared to reference 11.

Table 22

TEST 2-1, REGULATED-SET CEMENT STRENGTHS

Core #	Length	Dia	Compressive Str, PSI	Tensile Splitting PSI
1	5.1"	4"		384
3	5.1"	4"		456
4	5.0"	4"		218
2	8.0"	4"	1490	
5	8.1"	4"	1145	
6	8.1"	4"	1091	

e. Test 2-4

Because of the success of Test 1-4 SE, a further test in using reg-set infiltrated into prepositioned aggregate was attempted. Figure 123 illustrates the design intended for this test. Two tests were attempted, however, problems with the apparent shelf life of the reg-set material occurred. Even though no citric acid had been added as a retardant, the first slab poured failed to set up enough to allow load testing within the alloted 60 minutes. The slab was tested at 90 minutes and failed under a load of less than 30,000 pounds on the 12-inch plate.

For the second test it was suggested that the large aggregate underlying the prepositioned aggregate be mechanically compacted rather than depending on the raining method of placement. However, the test cylinders made during the initial pour showed a strength of less than 1,000 PSI in 24 hours and further testing with the remaining reg-set material was abandoned.

f. Advantages of Reg-set

Prior to the testing at Tyndall and WES, several distinct advantages of reg-set cement for use in the BDR program were envisioned. Reg-set could give excellent strength gains within an hour without degrading the long term strength of the material. By controlling the amount of active or ternary material, strengths of 1,000 PSI have been realized in 1 hour and up to 3100 PSI in 90 minutes. In addition, the set time could be controlled from 1 to 40

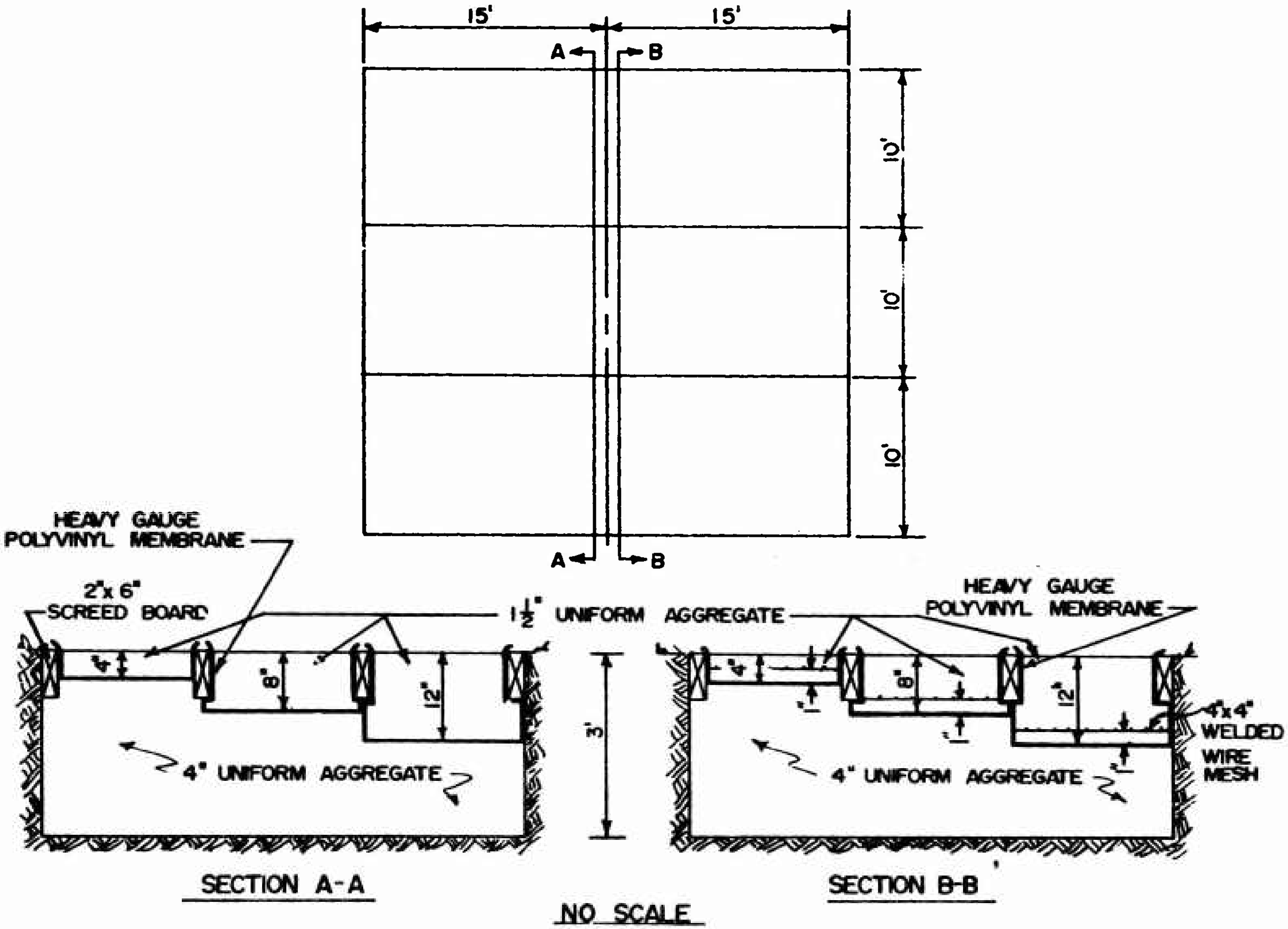


Figure 123. Reg-set Infiltration Test Section. Test 2-4

minutes by use of the proper retardant (citric acid) without fear of lowering the strength gain. These qualities were previously unavailable in a material that had the properties of Type I cement and could therefore serve as a permanent repair surface. This made it possible for the first time to use a material for an expedient repair that could also remain as a permanent repair. Although the Fast Fix cements had been heralded as capable of this role, they did not possess the strength and durability properties of ordinary Type I cement (ref. 10).

Other advantages of reg-set were thought to include: the ability to be used in cellular foam form as a backfill material, making both the cap and backfill similar in equipment requirements; the property of self leveling, making reg-set extremely easy to handle both as backfill and as a cap; finally, excellent economy in comparison to other fast setting materials. At present, the cost is about double that of Type I or III Portland cement, however, the cost of raw materials is only 10 percent more expensive. Most of the extra cost is a result of the smaller volume produced and with increased production could become significantly less.

g. Problems

Despite the promising advantages of reg-set, research and testing at AFWL, WES and Tyndall AFB identified several disadvantages of reg-set for BDR applications. Many are inherent in the material, others are due to shortcomings in the current state-of-the-art.

(1) Availability

Reg-set is patented by the Portland Cement Association, and licenses to produce reg-set have been issued throughout the world. Nevertheless, no manufacturer in the United States as of 1973 makes the material as a production item. It has been made by several companies in the past, however, production has ceased due to lack of demand and an accelerated demand for Types I and III cement (ref. 28). The situation abroad seems to be similar, with only token amounts being manufactured. Requirements for BDR kits would not be ample to alter this trend unless the material were shipped throughout the world from a few plants. Availability presented an especially large problem for the Tyndall Tests. The test conductor was forced to purchase an "experimental" lot from the manufacturer, Lone Star Cement.

(2) Specifications

As mentioned previously, the state-of-the-art in reg-set cements is fairly primitive. To date, no standard specifications for the material have been adopted by the American Society for Testing and Materials (ASTM). Because of this, several problems exist in any attempt to use the materials. The shelf life is unknown and undefined, as exhibited by the results of Test 2-4. One cannot be assured of getting similar materials from two different suppliers, or for that matter from one supplier at two different times.

(3) Time to Set Complications

Because of the dependence of set time on the temperature, controlling the set time is a complex problem. The time can be regulated under known temperature conditions to any period required, but the temperature environment for in place reg-set is anything but simple. The delivery temperature is dependent upon several factors, including the temperature of the water and dry cement as supplied to the mixer, the ambient temperature, and the size, roughness and length of the supply line. In addition, the supply line temperature contribution would tend to increase as reg-set is built up in the line and the pipe size is decreased, with a consequent rise in friction. Once delivered, other temperature factors including the ambient temperature, exposure to sun and reaction heat from previously placed reg-set alter the temperature of the newly delivered reg-set. These factors all must be accounted for to determine the amount of citric acid to be added to insure a given set time.

(4) Screeding

The set time problem ties in closely with the screed problem. Screeding of the material becomes critical for introducting satisfactory airfield surfaces, especially when the surfaces are to be a permanent part of the airfield. Screeding was a major problem in all tests performed. The requirement for formwork complicated the problem of repair and lengthened the time required. It was shown conclusively that reg-set is not self-leveling under the conditions required for satisfactory set time in the field. The screeding problem has not been satisfactorily solved.

(5) Logistics

The largest problem exposed by testing is the impossibility of the

logistics required for BDR usage of the material. Both in terms of equipment and in terms of supplying the reg-set and water, a large cumbersome problem is created. A 1-foot cap for a 750-pound crater requires 140 tons of cement and 18,000 gallons of water. Use of reg-set in the backfill increases this requirement tremendously, to as much as 230 tons of reg-set and 30,000 gallons of water for each repair. With the current requirement for having materials on hand for nine craters, this would mean a requirement for the storage on base of up to 2,070 tons of cement and the availability of 270,000 gallons of water. In addition, the supply of reg-set cement must be rotated because of the shelf life problem

Transporting the cement to the crater site in itself would be a monumental job, as would be the supply of water if it could not be piped to the site from a larger source.

(6) Equipment

As demonstrated by the many problems incurred at WES and Tyndall, commercially available equipment is not suited to the pumping rates and reliability required. A similar problem was encountered by ASD in the use of Fast Fix and led to the development of a large complex piece of equipment to do the job (ref. 8). That proved to be an impractical way of approaching the BDR problem. A requirement for reliability in water/cement ratio is not met by the present equipment. This was a distinct problem at WES, and of course causes unpredictable strength and set time errors. Additionally, present commercially available mixing and pumping equipment does not have proper safeguards against setting up of the material in the pump or supply lines if an interruption in the operation occurs. Once this happens, the equipment is useless until time can be expended to hammer out the set material.

(7) Pavement Flexibility

As discussed in section IV, it now appears that an expedient repair requires a tolerance for long term settlement. This requires flexibility in the repair cap and an easy technique for resurfacing of the repair when settlement does occur. AM-2 matting meets this requirement since it may be removed, base course added compacted and leveled as needed and the matting replaced. Reg-set would crack under large deflections and could fail during use. Repair would require time consuming removal of the material and replacement with similar material.

(8) Foam-System

The foam systems add still another complication when reg-set is used as backfill. Not only is extra equipment required, but protein foaming agent as well. In addition, no method of accurately controlling the foam density exists with current equipment. Still another problem that exists and has not been solved is the method of properly mixing together debris and foam when foam is used as a matrix. The first test at WES demonstrated that reg-set has a high surface tension value and that solid material does not mix easily with it.

(9) Thermal Radiation

As with all exothermic reactions, reg-set gives off heat. This can and has produced temperatures of up to 220 degrees F. This heat has been shown to be detrimental in the PVC module concept, and large placements of reg-set have not been tested to determine if the heat would be detrimental to the curing of the reg-set itself. This heat also creates thermal gradients easily capable of being detected by heat seeking weapons and other infrared equipment.

SECTION IX

PROPERTIES OF CRATERS IN PAVEMENT SYSTEMS

1. BACKGROUND

Extensive work in this area has been accomplished both in-house and by contract for AFWL, including studies documented in references 12, 13, 14, 15, and 24. Additional efforts are currently underway. To further the data base in this area, cratering parameters were carefully taken for all craters at the Tyndall AFB test site. Properties have been given when needed in sections III to VII, and pertinent drawings are included in appendixes III to VII. Properties are summarized in tables 23, 24 and 25. The important crater properties for repair consideration are defined in figure 124.

2. WEAPON PLACEMENT

Test 1-1, 1-2 and 1-3 were conducted utilizing craters created by the detonation of 750-pound M117 bombs placed below the pavement surface at the optimum Depth of Burst (DOB)[13]. Test 2-1 was conducted in a crater created by an M117 weapon placed in the repaired backfill of Test 1-1.

In Tests 1-1 and 1-2, the 16-inch diameter M117 weapon was placed in an 18-inch diameter drilled hole. The holes were drilled the day preceding each of the two events at a 30-degree angle to the vertical, thus simulating the "J" effect of air delivered penetrating weapons. The bottom of the drilled holes for Tests 1-1 and 1-2 were 11 feet 2 inches below the pavement surface. This placed the center of gravity of the 51-inch long weapons at a DOB of 110 inches. The holes were drilled through a square cutout left in the pavement during construction.

Because of stability problems in the sand subgrade in Test 1-3, the hole was vertical and drilled to a depth of 10 feet, giving the weapon a DOB of 95 inches. The hole for Test 2-1 could not be drilled because of the extensive amount of concrete debris in the backfill from Test 1-1. The hole was dug with a 660 Gradall and a plywood casing was placed into which the weapon fit. To insure coupling of the energy to the surrounding soil, the area around the form was backfilled with clay and concrete debris. The depth of the base of this box was 12 feet below the surface, putting the center of gravity of the weapon at 118 inches below the pavement surface.

Table 23

CRATERING INFORMATION, SOIL DENSITIES AND MOISTURE CONTENTS

	Location	Test #	Density	Moisture Content
TEST 1-1	Crater Bottom Uncompacted Debris Clay Rubble	1	116.6	14.1
		2	85.1	13.2
		3	114.1	14.5
		Average	105.3	13.9
	Beneath 8,500# Block Crater Bottom Clay Rubble		85.6	12.4
TEST 1-2	Elevation 12.5', Beneath True Crater Bottom Gray Sand		100.0	14.9
	Elevation 13.4, True Crater Bottom Clay Rubble	1	111.3	16.4
		2	108.2	16.8
		3	110.8	16.5
		Average	110.1	16.6
	Elevation 15.0, Apparent Crater Bottom Clay Rubble	1	88.4	14.0
		2	50.8	13.5
		3	102.8	14.6
		Average	80.7	14.0
	Crater Wall, 1/2 Way Up		87.7	14.4
TEST 1-3	Crater Bottom, Apparent		71.9	3.9
	Crater Wall, Apparent 1/3 Way Up		71.9	6.7
	Crater Wall, Apparent 2/3 Way Up		70.2	4.6
	Crater Wall, True 1/2 Way Up		76.1	6.7
TEST 1-4	Apparent, Crater, Bottom,	1-4 NE	90.3	4.1
		1-4 NW	74.8	4.9
		1-4 SW	103.8	6.0
		1-4 SE	92.8	7.8

Table 24

CRATERING RESULTS, TEST 1-4, 25 POUND C-4

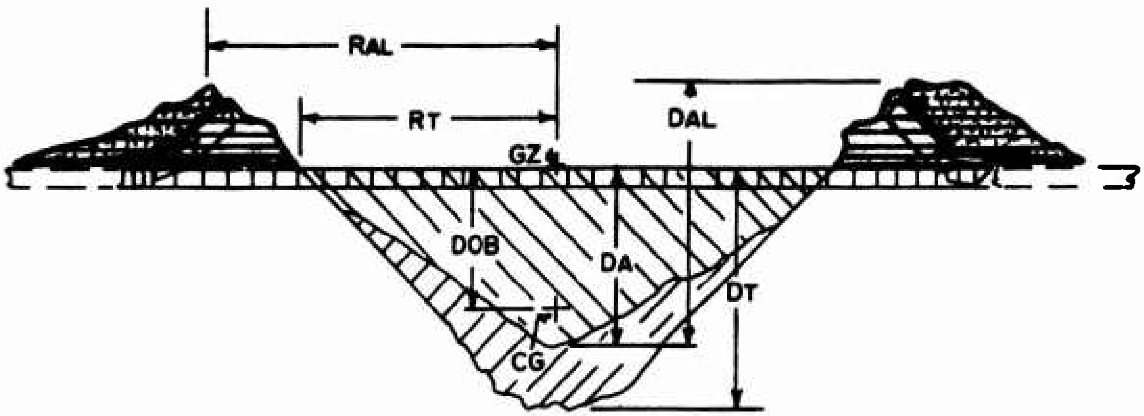
	1-4 NE	1-4 NW	1-4 SW	1-4 SE
Depth of Burst (DOB)	48"	48"	48"	48"
Elevations				
Ground Zero (ft)	25.72	25.70	26.82	26.85
Crater Lip (ft)	26.53	26.38	27.48	27.42
Apparent Floor (ft)	21.95	21.67	23.07	23.69
True Floor (ft)	21.10	20.82	21.41	22.36
Ground Water (ft)	15.38	15.38	15.38	15.38
Depths				
Apparent Crater Below Lip (Dal) (ft)	4.58	4.71	4.41	3.73
Apparent Crater (Da) (ft)	3.77	4.03	3.75	3.16
True Crater (Dt) (ft)	4.62	4.88	5.41	4.49
Apparent Radius (ft)	6.3	7.1	6.5	5.6
Apparent Lip Radius (ft)	7.3	7.8	7.3	6.5
Volume				
Crater Apparent (c.y.)	8.9	9.4	7.6	6.0
R to Mass Center (ft)	2.4	2.4	2.3	2.1
Ejecta and Upheaval (c.y.)	9.3	8.6	4.5	4.2
R to Mass Center (ft)	10.0	10.5	8.5	8.0
Repair Area (s.f.)	453	---	399	---

Table 25

CRATERING RESULTS, TESTS 1-1, 1-2, AND 2-1
750 POUND M117 WEAPON

	1-1	1-2	1-3	2-1
Depth of Burst (DOB)	110"	110"	95"	118"
Placement Angle (to vertical)	30°	30°	0	0
Elevations				
Ground Zero (ft)	26.90	26.32	25.68	26.60
Crater Lip (ft)	29.70	28.81	28.32	29.42
Apparent Floor (ft)	14.30	15.00	16.30	13.90
True Floor (ft)	---	13.40	---	11.40
Ground Water (ft)	14.88	15.20	17.20	15.46
Depths				
Apparent Crater Below Lip (Dal) (ft)	15.4	13.8	12.0	16.7
Apparent Crater (Da) (ft)	12.6	11.3	9.4	12.7
True Crater (Dt) (ft)	---	12.9	---	15.2
Heigth of the Ejecta (ft)	---	---	826	735+
Ejecta Spread (ft)				
North	423'	---	---	---
East	384'	---	---	---
South	361'	---	---	---
West	390'	---	---	---
Apparent Radius (ft)	20.9	21.5	15.6	---
Apparent Lip Radius (ft)	23.9	24.6	17.8	---
Volume				
Crater Apparent (c.y.)	261.5	245.0	107.6	---
R to Mass Center (ft)	6.9	7.1	5.1	---
Upheaval and Ejecta (c.y.)	228.0	202.4	130.5	---
R to Mass Center (ft)	29.0	30.0	22.7	---
Ejecta (c.y.)	---	129.6	---	---
R to Mass Center (ft)	---	33.6	---	---
Upheaval (c.y.)	---	72.7	---	---
R to Mass Center (ft)	---	25.3	---	---
Repair Area (s.f.)	3294.0	3342.0	2268.0	2002.0 (cap area)

DEFINITIONS, PAVEMENT CRATERING



— —	- ORIGINAL PAVEMENT SURFACE
DT	- TRUE CRATER DEPTH
DA	- APPARENT CRATER DEPTH, ORIGINAL SURFACE
DOB	- DEPTH OF BURST
GZ	- GROUND ZERO
CG	- CENTER OF GRAVITY OF WEAPON
(diagonal hatch)	- FALL BACK VOLUME
(reverse hatch)	- APPARENT CRATER VOLUME
(solid)	- EJECTA VOLUME
(vertical bars)	- PAVEMENT REPAIR VOLUME
(horizontal bars)	- UPHEAVAL VOLUME
DAL	- APPARENT CRATER DEPTH, LIP
RT	- TRUE CRATER RADIUS
RAL	- APPARENT CRATER RADIUS

Figure 124. Pavement Cratering Definitions

3. ANALYSIS OF DATA

a. 750 Pound Bomb Craters

Table 24 capsulizes data gathered from the four craters created by statically detonated 750 pound bombs. A comparision of the size crater produced in a sand subgrade, 1-3, versus those for clay subgrades, 1-1 and 1-2, shows the difference due to varying subgrade systems. A much larger fireball was observed during Test 1-3 and a larger overpressure was perceived. This very possibly indicated poorer coupling of the soil and energy than in Tests 1-1 and 1-2. The difference in placement of the M117 weapon, 95 inches for Test 1-3 versus 110 inches for Tests 1-1 and 1-2, could account for a portion of the 26 percent reduction in crater apparent radius and the 57 percent reduction in apparent crater volume. Reference 13 defines previous work done with 750-pound bombs, however, depths of burst this shallow were not tested. Reference 10 also includes data on 500-pound bombs, and the true soil crater volume, defined therein and somewhat analogous to the apparent crater volume, does drop off sharply with decreased depth of burst for detonations shallower than optimum. The apparent radius does not demonstrate a rapid drop off with reduction in depth of burst. All work in the above reference was performed in a silty-clay material. It is concluded that a much smaller crater can be expected from detonations in sand subgrade materials.

b. 25-Pound C-4 Craters

While no previous work in sand subgrades has included the M117 weapons, work done at Ft Sumner, New Mexico, included 25-pound C-4 charges in a sand subgrade (ref. 13). Information from that testing, done under an 11-inch concrete on a compacted natural silty sand subgrade closely matches the information in table 23 for Test 1-4.

c. Repair Requirements

(1) 750-Pound Bomb Craters

Tables 23 and 24 include the distance from the central axis of the crater to the center of mass of the crater or the crater debris (ejecta, upheaval). This allows an estimate to be made of the material movement required in backfilling. In crater 1-1 for example, the upheaval and debris would be moved 22.1 feet (29.0-6.9) on the average during the backfill process if all

the debris were used. Since the final foot of fill below the pavement would be select material, only 210 yards of the debris would be used as backfill. The remaining 18 yards would be spoiled to the side of the runway, along with the remaining pavement removed in creating the 3,294 square foot repair area. In the sand subgrade, crater 1-3, the debris and upheaval placed back in the crater would be moved 17.6 feet on the average. Only 79 yards would be used in the backfill process, with the remaining 51 yards on debris and all pavement removed in making the 2,002 square foot repair area spoiled. Another way of looking at the backfill process is that the clay subgrade craters would require (210 x 22.1) 4,641 CY-ft movement of debris backfill plus the placement of 122 CY of select backfill and the spoiling of about the same amount (122 CY) of material. The sand subgrade would require the movement of only (79 x 17.6) 1,390 CY-ft movement of debris backfill, placement of 74 yards of select fill and spoiling of about the same amount (74 CY) of material. The CY-ft backfill requirements of crater 1-3 are only 30 percent of the requirements for crater 1-1, with the select backfill and spoil in the sand subgrade being only 61 percent of the clay subgrade requirements.

(2) 25-Pound C-4 Craters

In comparison to the above, the average 25-pound C-4 crater in a sand subgrade would require the movement of 23 CY-ft of backfill, the placement of 16 CY of select backfill and the spoiling of an equal amount (16 CY) of pavement and debris. This amounts to only 1.6 percent, 21 percent, and 21 percent respectively of the backfill movement, select fill and spoil requirements for a 750-pound bomb crater in a sand subgrade, or 0.4 percent, 12.9 percent, and 12.9 percent respectively of a 750-pound bomb crater in a clay subgrade.

(3) Implications

The use of a 750-pound bomb in a clay subgrade creates significantly more work for repair than one in a sand subgrade if the crater sizes are not sensitive to the 15-inch variation in depth of burst. The repair volumes for 25-pound C-4 craters are small compared to those for the 750-lb weapons. However, the total time required for repair is more dependent on time consuming processes such as the removal of upheaved pavement than on the backfilling process, especially when one is not concerned with compacting to

eliminate the long term settlement problems.

d. Other Damage

In addition to the crater and upheaved pavement, severe horizontal stresses created large cracks in the pavement at points far beyond the limit of upheaval. These cracks are shown in the plan view drawings of the damage in appendixes III to VII. Figures 125 and 126 show the type of damage incurred. The pavement between the crater and the runway edge was pushed sideways due to a lack of support along the runway edge. In one case, the displacement between two adjacent pavement sections at the runway edge was 6 inches.

Figure 125. Pavement Cracking Outside Zone of Upheaval, Test 1-2

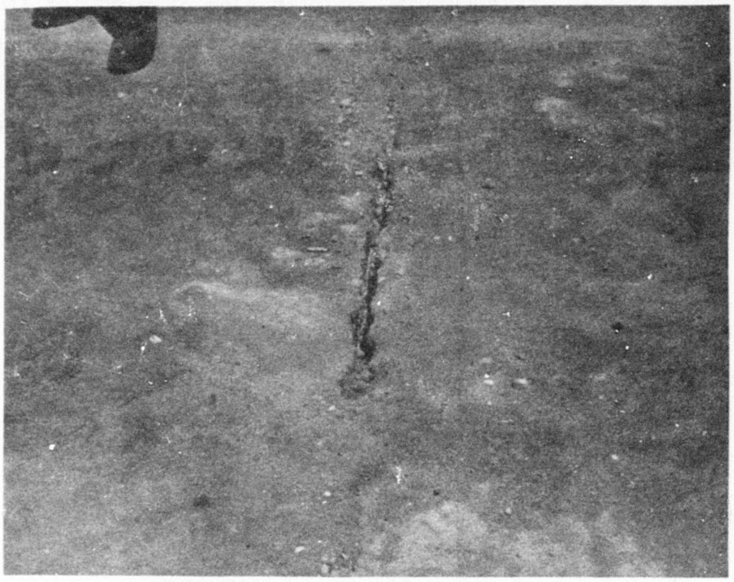


Figure 126. Pavement Cracking Outside Zone of Upheaval, Test 1-1

SECTION X

CONCLUSIONS AND RECOMMENDATIONS

1. CONCLUSIONS

The repair of an optimum size 750-pound M117 bomb crater by the current AFM 93-2 technique could not be completed after 5 hours and 45 minutes due to the poor procedures outlined in AFM 93-2, lack of proper repair experience, unsuitable vehicle equipment, and poorly selected back up equipment, such as that used for attachment of the ramp system. In view of the excessive deflections detected during load cart testing, the patch would have been unusable by F-4 aircraft.

The results of Test 1-1 clearly indicated the requirement for changes in AFM 93-2, Chapter 5. Some of these changes have been made, while others must still be accomplished. Personnel related items, such as poor choices of job sequence and mistakes in operations, pointed up the need for both more extensive training and clarification of and changes to procedures outlined in AFM 93-2. Failure to clearly mark out the work area resulted in failure to limit the amount of work to be done to the absolute minimum. A misunderstanding of the extent of the pavement to be removed severely lengthened the repair time and damaged the morale of the repair team. Even though this team had the requisite training according to AFM 93-2, their experience with optimum size craters explosively produced was non-existent. Failure to keep equipment productive and to stockpile material added to length of repair. Late in the repair, operator fatigue dropped the equipment efficiency to an unacceptable level. Each of the above items could be changed through proper revisions to AFM 93-2. Problems with the equipment utilized demonstrated that it was not well suited to the repair procedure. In general, the equipment was undersized for the cleanup and backfill role. Larger equipment would have been able to accomplish these chores in less time, and with possibly less peripheral damage to the pavement. The equipment was unable to deal with the large amounts of upheaval, and in some cases extended the damage while trying to remove upheaval. The crane included in the kit was of no use in any capacity. Equipment for proper compaction and for adding moisture to the select material was not in the equipment package. Hauling of select

material to the site waas hampered by the size and number of the haul trucks. This can be solved by temporary stockpiling near the repair. The final grading of the patch was of less than desirable quality. In this operation and others, the use of an equipment director or groundman to direct the equipment from the ground and to serve as an alternate operator for relieving the primary operator was needed.

The attachment of the AM-2 matting was not ompleted because of the inability to drill the proper holes with the equipment provided and the inability of the expansion bolts provided to hold in the asphalt overlay material. The inclusion of a rotary hammer electric drill in the BDR kit solves this problem, although a proper expansion bolt should be designed. The inability of the ramp sections to follow breaks in slope, such as runway vertical curves and drainage cross slope created unnecessary problems.

a. Backfill of Bomb Damage Repair Craters

The quality of the Test 1-1 debris backfill showed that under many conditions the debris backfill need not be carefully placed. However, this was in a clay at near optimum moisture. Such conditions do not exist at all BDR Bases. Each base or group of bases must be treated differently in this respect, depending on the subgrade conditions. Compaction may well be required at some bases in the debris backfill, while others may be forced to use only select backfill. One thing is certain, compaction equipment and a means of adding the optimum moisture for compaction is an absolute requirement for the select fill. In Test 1-2, the select fill quality was directly related to this, and could have withstood both limited F-4 traffic and F-111 traffic without a wearing surface.

Regardless of the quality of the backfill, whether it is select or debris, Test 1-2 demonstrated that consolidation, or long term settlement, must be lived with, unless one is prepared to excavate the crater walls and floor until good or competent material is reached. This settlement is not drastic, but the use of flexible and repairable capping systems is required. Consolidation and load settlement within the debris backfill illustrated that compaction below about the 6-feet-below-surface point is not needed since the load below this point is minimal for aircraft up to the F-111 weight class. This is not true for heavier cargo or bomber aircraft.

Test 1-2 further yielded the information that there is no rebound of the debris material following loading, which indicates that a repairable surface is an absolute requirement on this type backfill.

b. BDR Equipment

The initial reaction to crater repair is that it is mainly a job involving extensive backfilling. In actuality the physical placement of backfill is not as time consuming a problem as the removal of damaged pavement. Test 1-1 showed the current equipment to be undersized for the design threat. Test 1-2 and 1-3 were used to develop a new package which could lower the repair time of an explosively formed crater to 2 hours and 45 minutes. This package has only a 7 percent cost increase involved under some situations. The package is centered around a large high horse power, maneuverable, rubber-tired dozer. Use of this package would involve no increase in manpower, yet would provide adequate compaction equipment for the select fill material.

This package was selected from equipment available at AFCEC for field testing. An FY75 AFWL project is seeking to identify other equipment which may be even more suited to the BDR task and which could further reduce the repair time requirement.

c. Small Craters

The use of small penetrating weapons could cause an increase in the effort required for runway repair by up tc 500 percent. Use of the current USAF BDR equipment showed that one piece of equipment working on one crater was optimum. Larger equipment was not particularly well suited to small craters, although it was acceptable. The large problem would be the assembly of numerous small mats, all of which must be 54-feet wide. The interaction between aircraft and numerous 1½-foot high mat surfaces is unknown.

d. Regulated-set Cement

The logistics requirements for placement and storage are extremely large. In addition, with the exception of the infiltrated aggregate cap, no reg-set cement system was found to be workable. The excess heat generated in the curing of the large masses of this material made it unworkable for large repairs, although it may have application for smaller repairs.

e. PVC Module Concept

This concept was essentially designed with the belief that the backfill of the crater was the major consumer of time in the repair process. It was found that the removal of the damaged pavement is actually the major time consumer. In addition, the fact that the modules have no simple integral capping makes the advantages of the modules small in comparison to the disadvantages. The incompatability of regulated-set and other cementitious materials and the PVC modules is unresolved.

2. RECOMMENDATIONS

a. AFM 93-2

As of this writing, revisions to AFM 93-2 are in process. These revisions encompass many of the solutions to problems discussed in the conclusions but not all. Revisions badly needed in AFM 93-2 include the definition of and order of accomplishment of the tasks in the basic repair, the deletion of equipment such as the 20-ton crane, addition of compaction equipment for the select fill material and the inclusion of tactical radios in the BDR kit. Improvement of the ramp attachment system must be provided for, and in this connection a research and development effort to define the forces on the attachment system and to develop a suitable expansion bolt should be high priority. A study of the roughness resulting from the ramp is being conducted at AFWL and should be continued.

b. Training Program

Regardless of the end BDR process, a comprehensive training program which familiarizes personnel with damage resulting from the actual threat should be instituted. The making of a training film at the FY75 BDR tests being conducted at Tyndall AFB is an excellent beginning, but will not be an able substitute for actual field experience. Certification of the key personnel in the BDR team should be a prominent part of the program.

c. Equipment Package

A new equipment package consisting of equipment more suitable for the design threat of 750-pound bombs should be adopted. If repairs based on debris backfill and mat systems are to be utilized in the future, this upgrade of equipment is essentially the only way to reduce the total repair time. Items included in the suggested repair process and equipment package

could be used in other than the specific package designed. These include the use of equipment directors or groundmen, the inclusion of appropriate water and compaction equipment and the upgrading of the team chief consistent with the added responsibility and complexity of the repair procedure.

d. Small Crater Threat

Because of the poor ability to deal with threats other than the design 750-pound craters, extensive work should be concentrated on determining the existing threat and planning for repair of threat items, such as small craters. Ability to repair three 750-pound craters is of little use if the runway is damaged by an equivalent payload of 5-pound or 15-pound penetrators. The AM-2 airfield patch system is particularly unsuited to the repair of many small craters.

e. Other Research Efforts

Results of the testing demonstrated a need for research efforts in various areas. These include detailed determination of the allowable roughness of the repair since roughness is a function of the time allowed for repair; improvement of the capping system, possibly eliminating the requirement for the cumbersome AM-2 airfield patch; determination and design if necessary of optimum equipment for the equipment-heavy tasks of BDR, such as damaged pavement removal; study of the AFM 93-2 method under conditions more adverse than those in the FY74 testing; and finally, a continuation of efforts to find advanced repair methods able to trim the repair time to the one hour goal. Many of these efforts are currently being pursued by AFWL, however, the limitations of funds and personnel does not allow for the active research program necessary to insure proper combat repair capability in the future. It is recommended that an increase in personnel and funding commensurate with the importance of the BDR function be made.

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APPENDIX I

TEST 1-1, TIME SEQUENCE LOG

1200 Begin test
1202 1 arrives with OIC, NCOIC and crater NCOIC

End Operation 1, Begin Operation 2

1204 11, 12, 13 arrive and begin clearing north to south
1205 9 and 10/15 combination arrive and begin clearing north end of pavement for AM-2 assemblage area
13 observed pushing into crater
1207 3 plus air compressor arrives
1210 9 now pushing east to west to clear AM-2 area
1212 8 arrives on site and begins working south end
1213 11, 12, 13 and 8 now pushing into crater
1215 14 on site
1223 matting crew arrives
1225 2 with BDR kit on site

Begin Operation 5

1230 11 begins unloading BDR kit
1231 8 partially in crater
1237 14 positioned at crater
1239 9 working on east side
1240 8 can go all through crater
1242 14 working on crater
1244 12, 13 and 8 idle to allow 14 working room
1249 8, 12 operating with 14, 8 in crater
1250 key lock placed
1255 9 working on south end
1257 14 only standing by
1259 first AM-2 going down
1300 crater 2/3 to 3/4 full
1301 BDR kit completely unloaded
1305 14 leaves site
1307 13 leaving site for stock pile
1308 12 removes first debris from site to dump area
1309 9 working on north end
1310 AM-2 dismantled
1322 11, 12, 8 participating in debris removal

End Operation 2, Begin Operation 3

1325 no filling being done, only debris removal
1328 hole 90 percent, 11 and 12 working edges to center for subgrade
1332 11 and 8 working in hole for compaction
1342 11 and 12 breaking off heaved pavement
1350 5 arrives with first load of select and stands by

1351 4, 5, 7 standing by with select material
1351 OIC begins checking pavement tolerance
1400 13 returns to site
1409 13 off-loads tamping equipment (never used)
1411 13 moves tamping equipment to crater
1416 13 returns to stock pile
1428 3 standing by loaded with 4, 5, 6, 7
1431 troop labor begun on final crater work
1445 11, 12, 13 standing by, 8 working in crater trimming subgrade and compacting
1451 12 and others bringing in sand fill (no suitable ejecta available)

End Operation 3, Begin Operation 4

1456 first select fill dumped
1500 8 still in crater
1501 tow bar attached to mat

End Operation 5

1506 select fill being pushed into crater
1508 8 leaves crater and begins dressing shoulders
1512 9 grading select off lip into crater
1522 12 compacting select fill in crater
1525 5 first truck to bring coarse wrong material
1539 10/15 sweeping again
1628 2 trucks select arrive and are held (select haul complete)

End Operation 4, Begin Operation 6

1636 11 and 12 attached to patch
1646 mat pulled longitudinally into position
1656 mat pulled into final position
1700 generator positioned for drilling anchor holes
simulated vacuum sweeper started
1745 holes drilled into asphalt only, test terminated

End Operation 6

Number	Vehicle Listing by Test Number
1	Truck, Pickup, ½ Ton, GED 4x2
2	Truck Tractor, 10 Ton, GED, 6x4
3-7	Truck Dump, 5 Ton, 4x4
8	Tractor, Full Track, SZ 4
9	Grader Motorized, 6x4
10	Tractor, Industrial, Wheeled, Sz 5
11-13	Loader, Scoop, Tired, 2.5 CY
14	Crane, Truck MTD, 20 Ton
15	Sweeper, Rotary Towed
16	Sweeper, Vacuum, Self-propelled (simulated)
17	Compactor, Vibrator, GED

APPENDIX II

TEST 1-2, INSTRUMENTATION PLAN

INSTRUMENTATION PLAN

BOMB DAMAGE REPAIR

ASSESSMENT

WRITTEN BY

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CHIEF, SYSTEMS ENGR. SECT.

APPROVED BY

Giles W. Willis

LT. COL. GILES W. WILLIS, JR.
CHIEF, EXPERIEMENTAL BRANCH

APPROVED BY

Lawrence D. Hokanson

CAPT. LAWRENCE D. HOKANSON
TEST DIRECTOR

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3. CALIBRATION OF SENSORS	222
4. INSTALLATION OF SENSORS	226
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2.1	Functional Diagram BDR Measurement System	220
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1. INTRODUCTION

1.1 The purpose of this test is to provide instrumentation to determine the settling effects of ejecta and backfill used to rapidly repair runway bomb craters. One instrumented test will be conducted at Tyndall AFB, FL using variable reluctance sensors to measure relative displacement of ejecta and backfill material subjected to surface static loads.

1.2 The test bed is a crater produced by a 750 lb. bomb placed to simulate a penetration type weapon. Figure 1.1 is an elevation drawing of a typical bomb crater showing maximum number of sensors required. Note that the true crater is filled with material that falls back after the bomb explosion to form the apparent crater. A small portion of the fall back material must be carefully removed to allow installation of the sensors. The signal cables must be protected from damage during the backfill operation with 3/4-in I.D. garden hose.

1.3 Figure 1.1 shows the desired placement of sensors. The important measurements are from the top of the crater down to just below the apparent crater line. Placement of sensors much below the apparent line may not be pratical or even productive of significant data. The actual number and location of sensors will be determined at the test site.

1.4 The following is a list of equipment that is required to perform calibration and installation of sensors. It does not include items needed for digging in crater material or for handling and tamping of fill material:

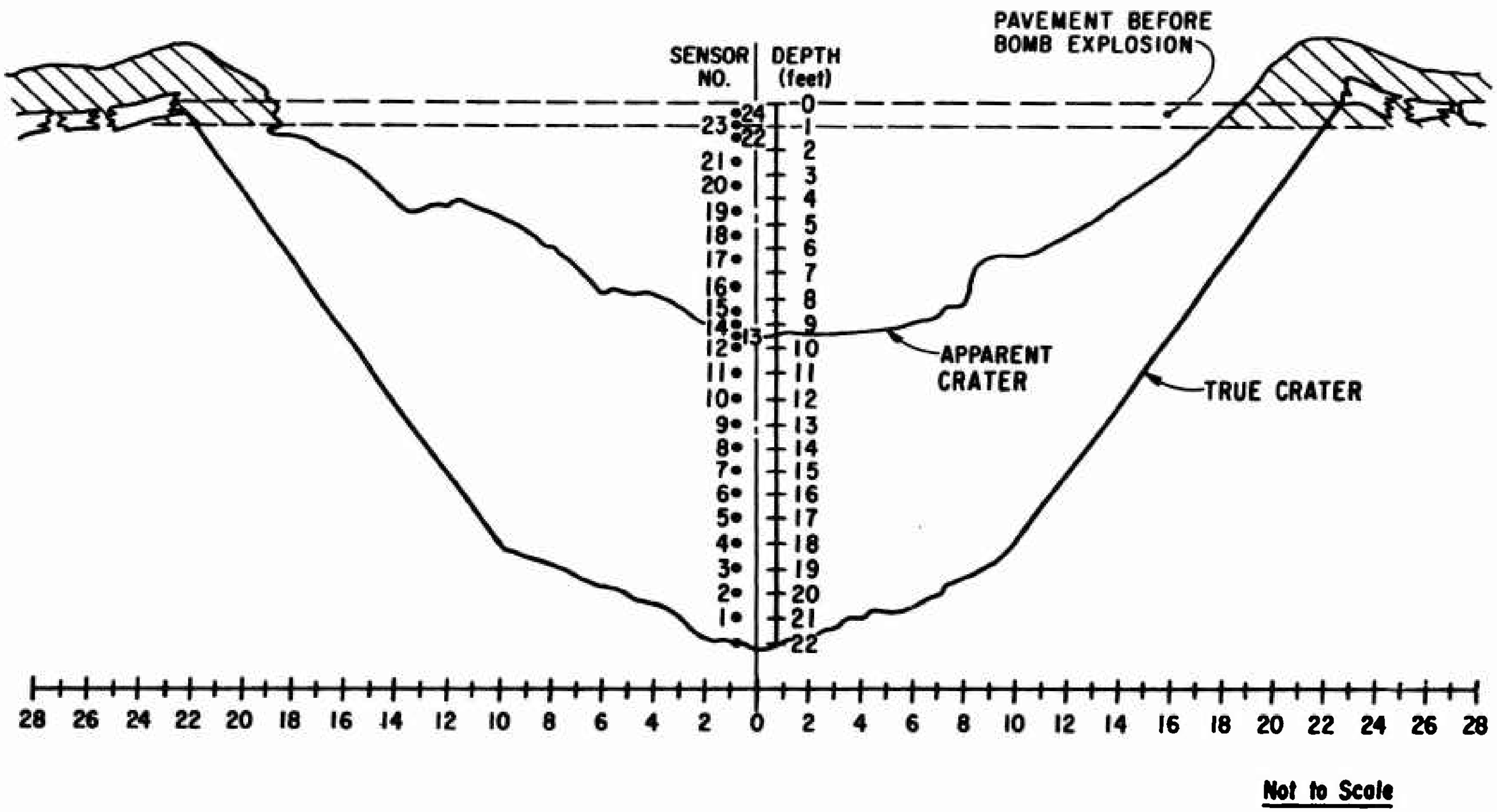


Figure 1.1. Typical Bomb Crater

EQUIPMENT NEEDED

1. 1 each; Bison Strain Gage Console Model 4101A
2. 30 each; Bison Sensors Model 4044
3. 1 each; D V M with 0.01-Volt Accuracy
4. 1 each; Hand Level - 6"
5. 1 each; 1/4 - in, diam, 30 in. wooden dowel
6. 1 each; Calibration fixture with spacers
7. 30 rolls; 3/4 - in. I. D. garden hose - 50 ft. lengths
8. Surveying Equipment (Optional)
9. String for running reference line across crater

2. DESCRIPTION OF INSTRUMENTATION

2.1 The instrumentation consists of a Bison Instruments Model 4101A Portable Soil Strain Gage Console (referred to as the console) and pairs of inductive discs (referred to as the sensors). The console measures the electro-magnetic coupling between pairs of sensors. By previous calibration of sensors the soil displacement between the sensors can be accurately determined. By using a specially designated switching box, pairs of sensors placed in a vertical line can be switched in and out to measure vertical displacement and soil strain in the test bed.

2.2 Figure 2.1 is a functional diagram of the measurement system. The sensors are 4 inches in diameter and are normally spaced from 4 to 16 inches apart. Sensors in this test will all be spaced 6 or 12 inches apart. The Bison Instruments Soil Strain Gage Model 4101A instruction manual gives complete descriptive and operational information on the strain gage system. It should be thoroughly studied before using the equipment or before installing sensors in the test bed. Figure 2.2 shows the internal wiring of the sensor box.

2.3 The sensors are specified to withstand 6 psi water immersion for 24 hours. This is equivalent to 12-foot depth of water. For additional watertight integrity the sensors will be coated with Scotchcast epoxy. The Scotchcast is brushed on the seams of the sensors and around the cable entry to the sensor.

2.4 Electrical inspection of the sensors is accomplished during the calibration procedure. A zero-volt null cannot be obtained if the sensors are electrically defective.

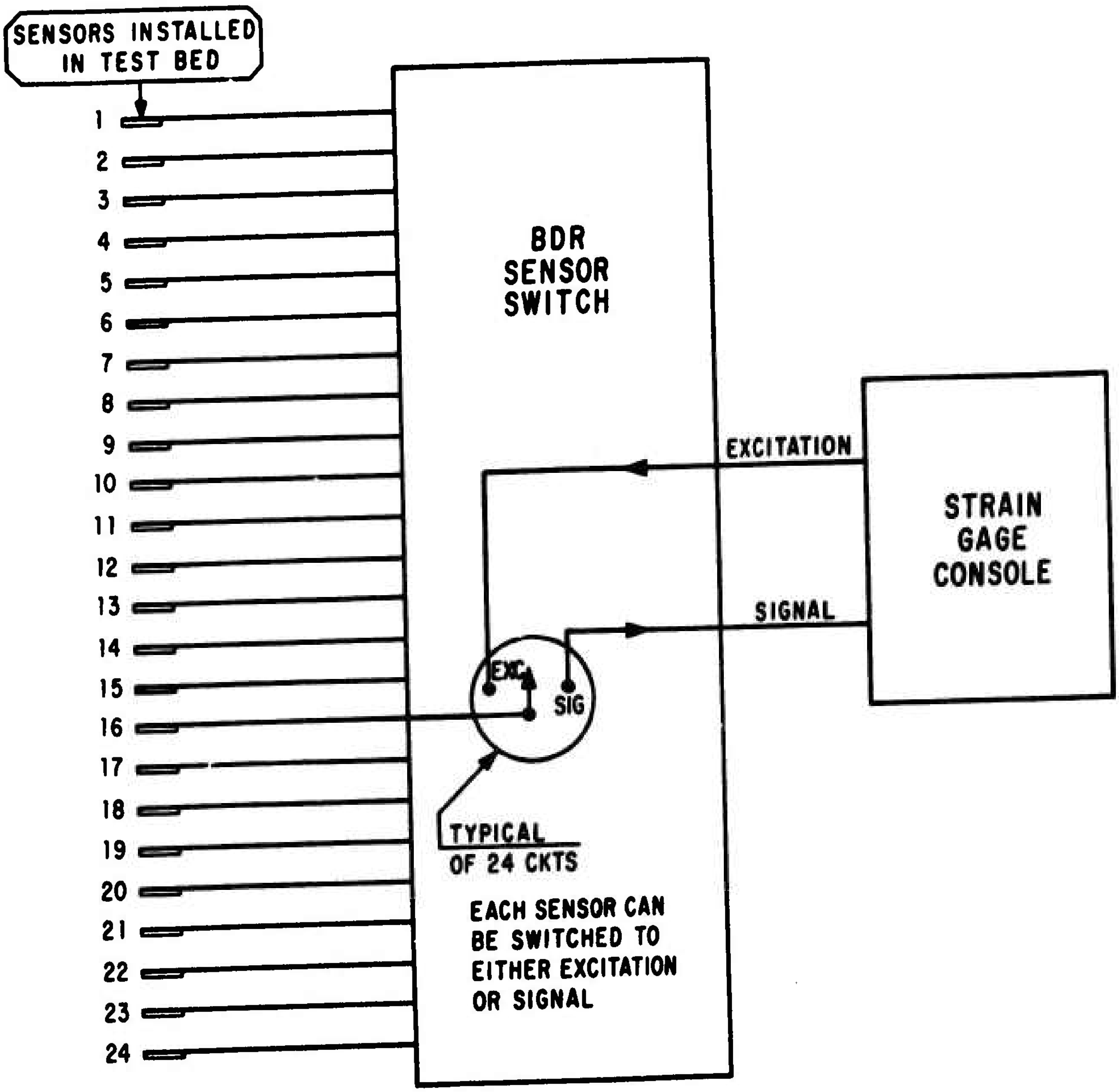


Figure 2.1. Functional Diagram BDR Measurement System

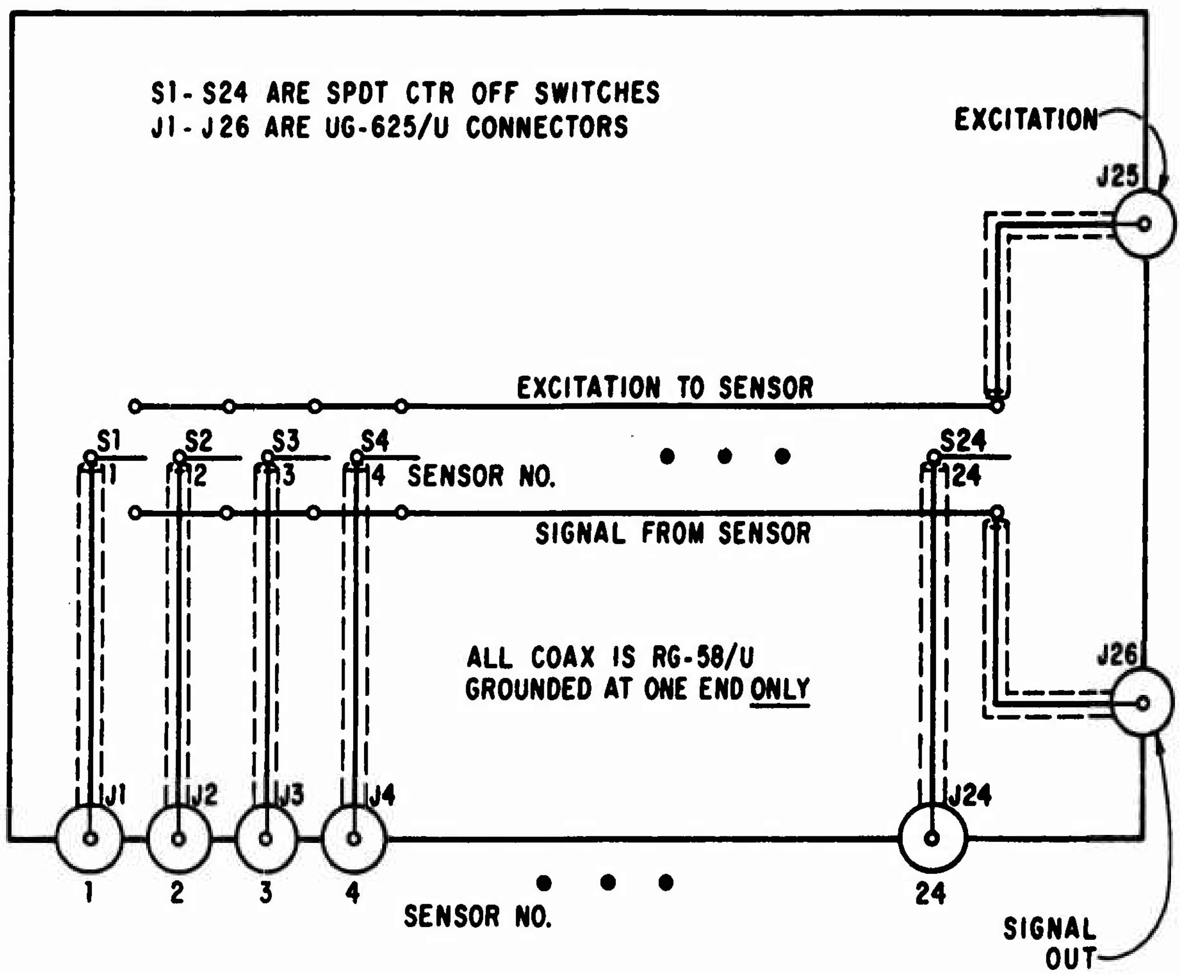


Figure 2.2. Schematic Diagram BDR Sensor Switch Box

3. CALIBRATION OF SENSORS

3.1 Sensors are calibrated in pairs. Therefore, measurement number designations will be the designation of sensor pairs, i.e., 1-2, 2-3, 3-4,... and 23-24. Each pair of sensors shall be calibrated by the "dial calibration" method. A special fixture is provided for calibration as shown in Figure 3.1. This fixture with accurately machined spacers allow calibration for the spacing dimensions called for on the calibration sheet. For maximum accuracy all sensor pairs should be calibrated.

3.2 Follow steps below for dial calibration of sensors:

a. Permanentaly mark 24 sensors on corresponding faces with serial numbers 1 through 24.

b. Setup a sensor pair on the calibration fixture so that the distance between corresponding faces is 12.75 inches.

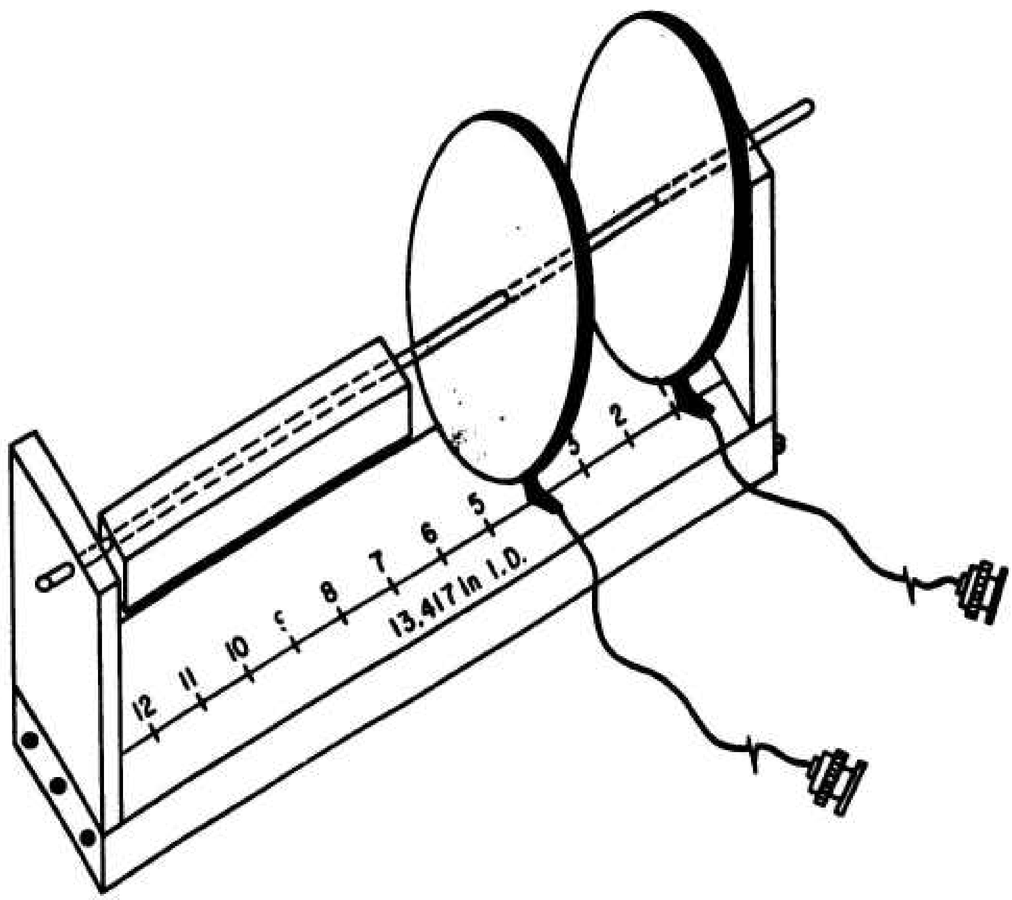
c. Connect digital voltmeter to "RECORD OUTPUT" jack of console.

d. Set CAL signal dial at 1000. Check phase and amplitude balance, adjusting if necessary. Adjust sensitivity so that meter deflects full scale (100 to the left of null position when calibrate switch is depressed.)

e. Check battery on console and set for operation in the internal mode and warm-up for five minutes.

f. Connect the lower number coil to OSC OUTPUTS connector and the other coil to SIGNAL INPUTS connector on the console.

g. Adjust AMPLITUDE dial for a zero-volt null balance on console meter or on digital voltmeter sensitive to about 0.01 volts on the 10 volt scale.



Scale: 5/16in = 1in

Figure 3.1. Calibration Fixture

h. Depress NULL switch while adjusting PHASE control for a zero-volt null.

i. Repeat steps f and g until zero volts is obtained.

j. On calibration sheet (Figure 3.2) fill in heading and record AMPLITUDE dial reading for the 13-inch spacing.

k. Repeat the balancing procedure for other spacings called for on the calibration sheet and record dial readings.

Name of Operator______________________________ Date______________

Measurement Numbers (Sensor Pair Serial Nos.)__________,__________

DIAL CALIBRATION

Spacing	Dial Reading	Spacing	Dial Reading
13.00		7.0	
12.75		6.75	
12.50		6.50	
12.25		6.25	
12.00		6.00	
11.75		5.75	
11.50		5.50	
11.25		5.25	
11.00		5.00	

Name of Operator______________________________Date______________

Figure 3.2. Sensor Calibration

4. INSTALLATION OF SENSORS

4.1 The following instructions will serve as a suggested method of installing sensors. As this is a one-time situation, the problems that occur at the test site cannot be anticipated.

Ejecta that has fallen back into the true crater will be partly excavated to allow installation of sensors. The depth of excavation will depend on the water table level and equipment available at the test site. Sensors must be placed in fine-grained material such as sand or soil to assure a fixed position during placement. Fifty-foot lengths of 3/4 - inch I. D. plastic hose are available for protecting sensor cables from abrasion or damage during crater filling operations.

4.2 For installation of sensors, follow the instructions in Section VII of the Bison Instruction Manual. Prepare a well tamped, solid base for the bottom most sensor and measure its depth below the crater top reference surface accurately. This can be done with standard surveying techniques using a level and rod. This can also be done by running a taut string across the reference surface and measuring the distance down to each sensor. Use a thin wooden dowel or plastic rod calibrated in length to determine spacing between sensors. This device should be removed as each successive sensor is placed. Record location information on instrumentation list (Figure 4.1).

4.3 After all of the sensors have been implaced, the entire system is connected as shown in Figure 2.1. The system is now ready for acquisition of data.

SENSOR NO.	DESIRED DEPTH BELOW REFERENCE SURFACE - ft	READING ON SURVEYOR'S ROD-ft	DEPTH OF SENSOR BELOW REFERENCE SURFACE-ft
1	21		
2	20		
3	19		
4	18		
5	17		
6	16		
7	15		
8	14		
9	13		
10	12		
11	11		
12	10		
13	9.5		
14	9.0		
15	8.5		
16	7.5		
17	6.5		
18	5.5		
19	4.5		
20	3.5		
21	2.5		
22	1.5		
23	1.0		
24	0.5		

Location of Test____________________Date_______________

Names of Operators________________, __________________

Inspected by____________________________________

Figure 4.1. Instrumentation List

5. ACQUISITION OF DATA

5.1 With the system connected as shown in Figure 2.1 turn on power to the Bison Soil Strain Gage Console and let warm up for five minutes. Then follow steps below for acquisition of data.

a. With no loading applied to test bed, sequentially switch in adjacent pairs of sensors and obtain a zero-volt null balance and record the AMPLITUDE dial reading on the data sheet (Fig. 5.1).

b. With various loading steps applied to the data sheet, zero-volt null each sensor pair and record AMPLITUDE dial reading on data sheet and record the loading weight for each series of sensor readings.

5.2 Upon completion of test, submit to Captain L.D. Hokanson, DEZ, Ext. 3511, the following:

1. Cover Sheet (Figure 5.2)
2. Copies of all sensor calibration sheets
3. Copy of measurement list
4. Copies of data sheets
5. Written notes or comments on any aspects of the test.

5.1 The originals on all the above information will be kept on file in the Quality Control Section of AFWL(DEX) for one year after completion of test.

		TEST BED LOADED		
SENSOR PAIR	NO-LOAD DIAL READING	______LB DIAL READING	______LB DIAL READING	______LB DIAL READING
1-2				
2-3				
2-4				
5-6				
6-7				
7-8				
8-9				
9-10				
10-11				
11-12				
12-13				
13-14				
14-15				
15-16				
16-17				
17-18				
18-19				
19-20				
20-21				
22-23				
23-24				

Figure 5.1. Data Sheet

BOMB DAMAGE REPAIR

ASSESSMENT DATA

CONTENTS

1. CALIBRATION SHEETS
2. MEASUREMENT LIST
3. DATA SHEETS
4. COMMENTS

LOCATION OF TEST ______________________________

DATE OF TEST ________________________

PROJECT NCO _________________________

Figure 5.2. Bomb Damage Repair Assessment Data

APPENDIX III

SITE AND TEST DRAWINGS, TEST 1-1

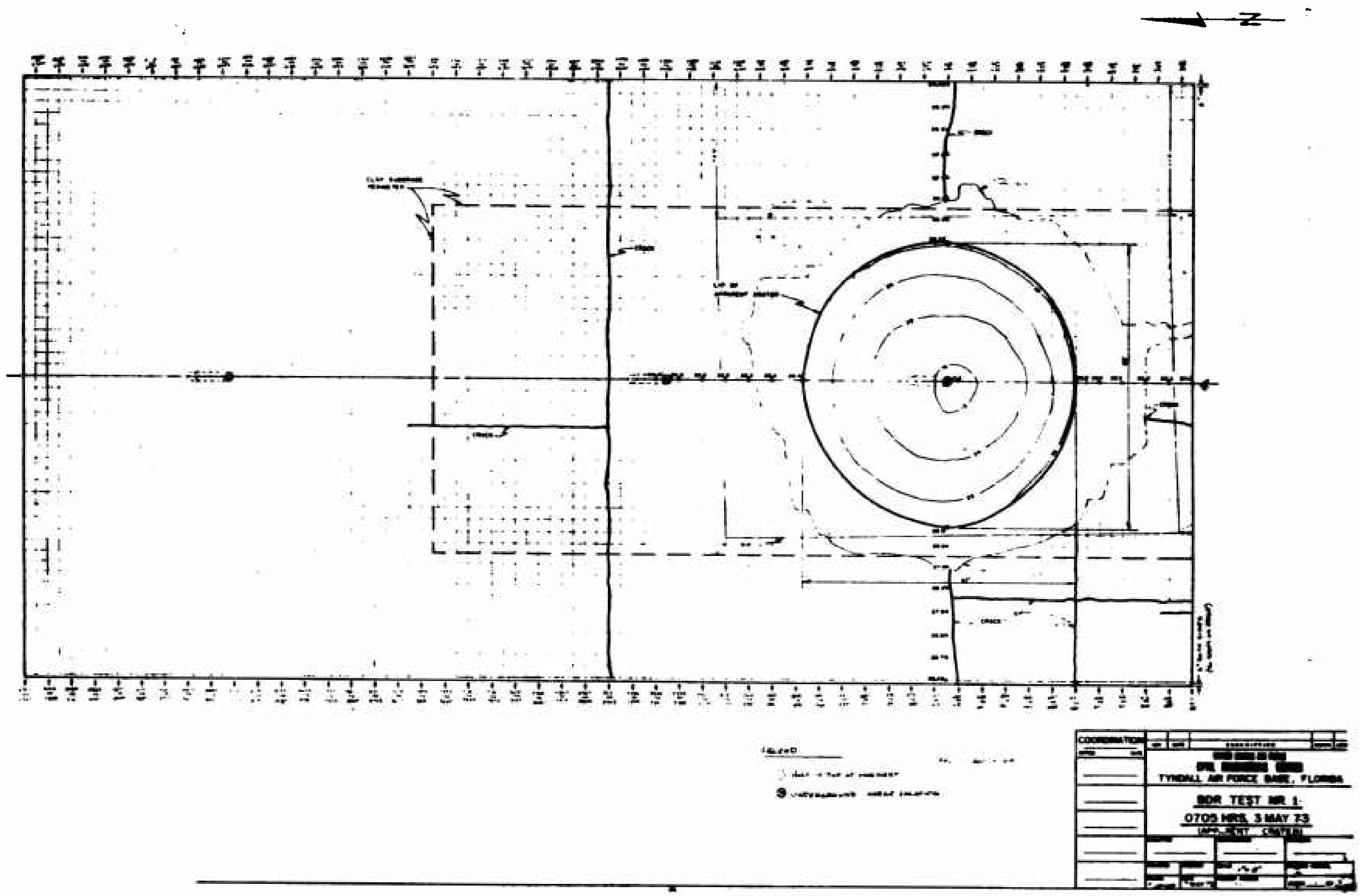


Figure 127. Crater Contours, Repaired Perimeter and AM-2 Airfield Patch Placement, Test 1-1

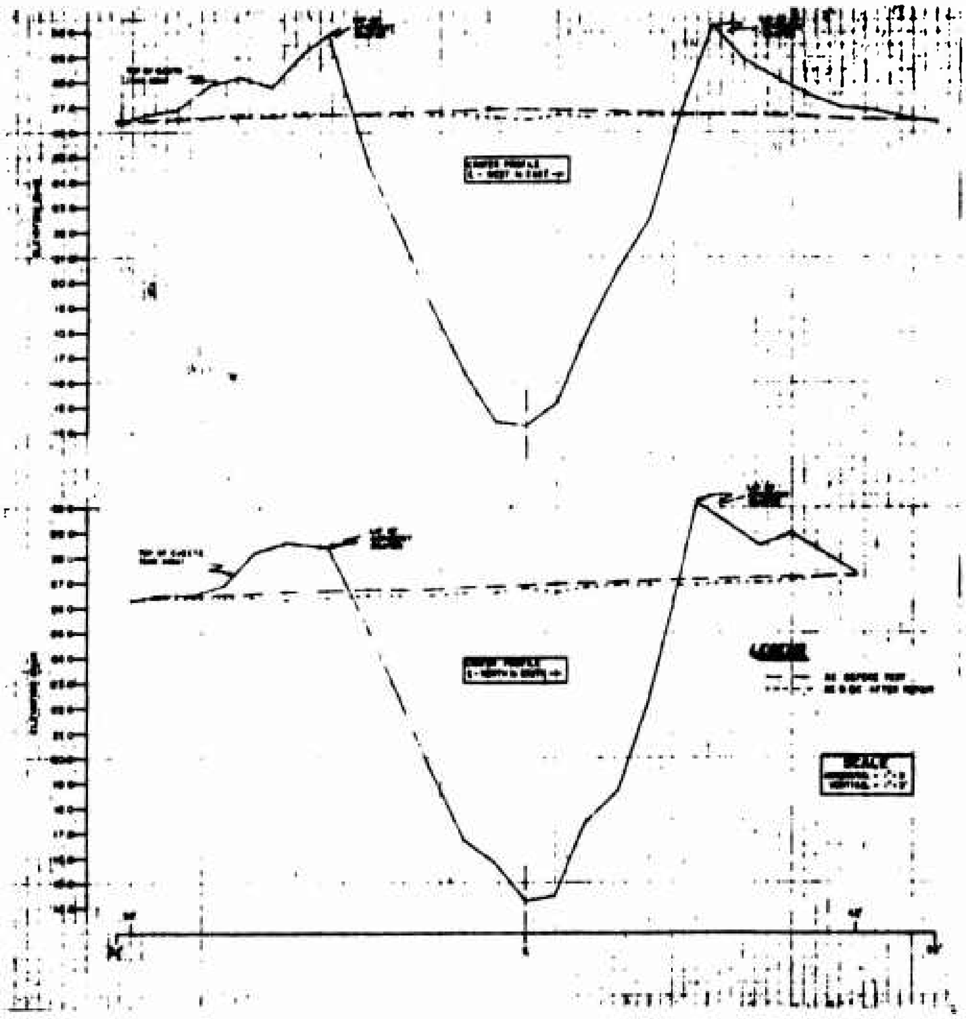


Figure 128. Crater Profiles, Test 1-1

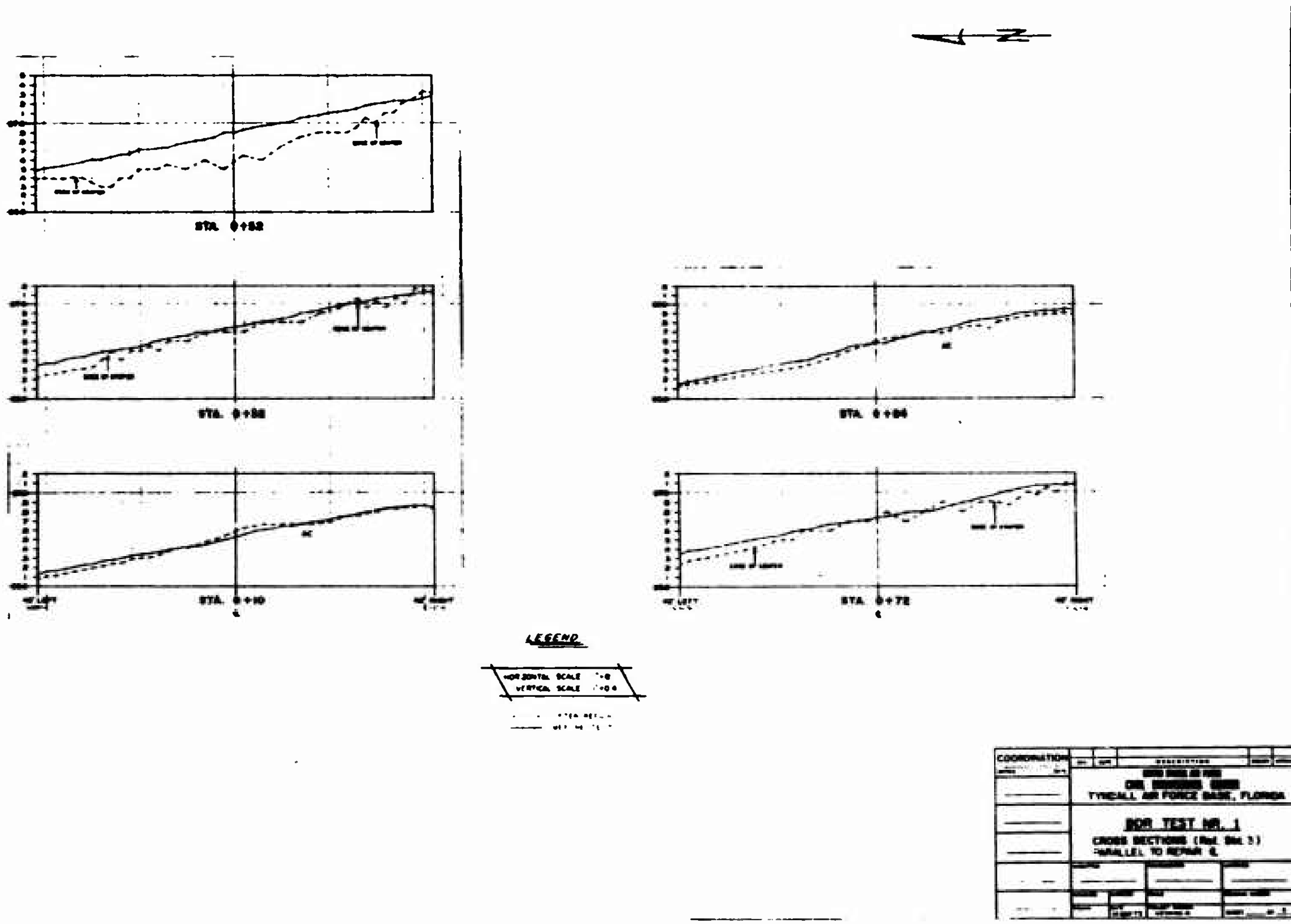


Figure 129. Cross Sections of Repaired and Original Pavement Surface, Parallel to the Repair Centerline, Test 1-1

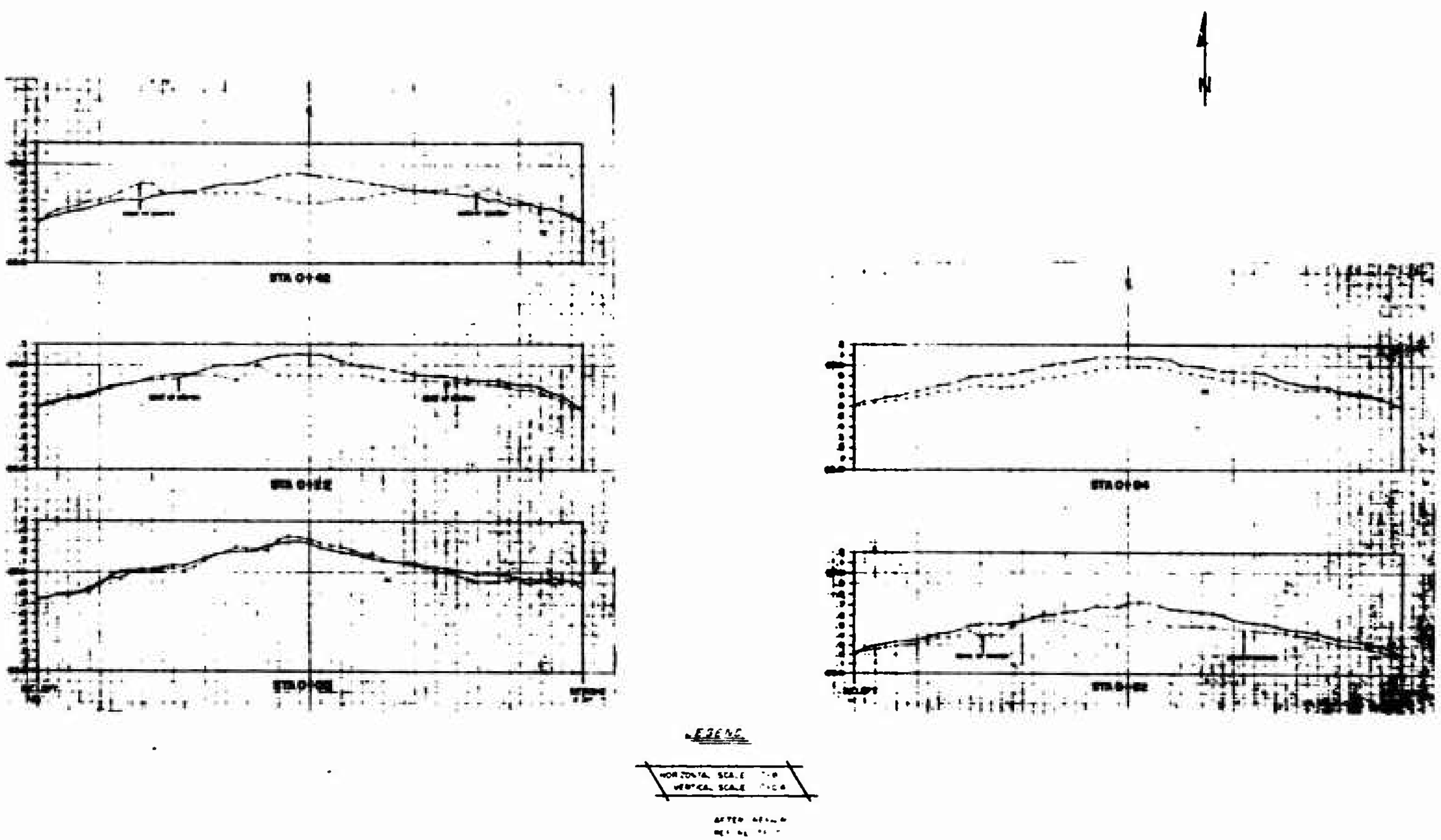


Figure 130. Cross Sections of Repaired and Original Pavement Surface, Perpendicular to the Repair Centerline, Test 1-1

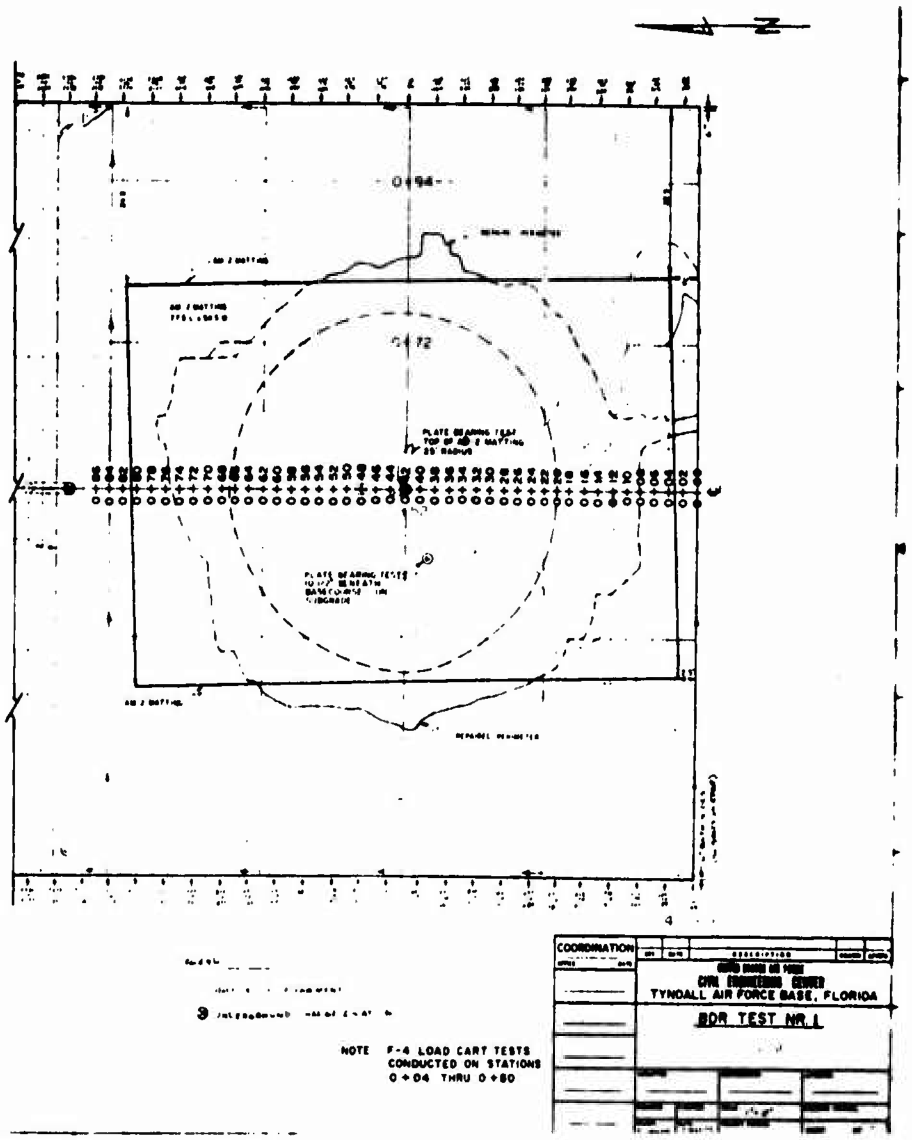


Figure 131. Plan View of the Repaired Perimeter, AM-2 Airfield Patch Placement and Stationing, Test 1-1

APPENDIX IV

SITE AND TEST DRAWINGS, TEST 1-2

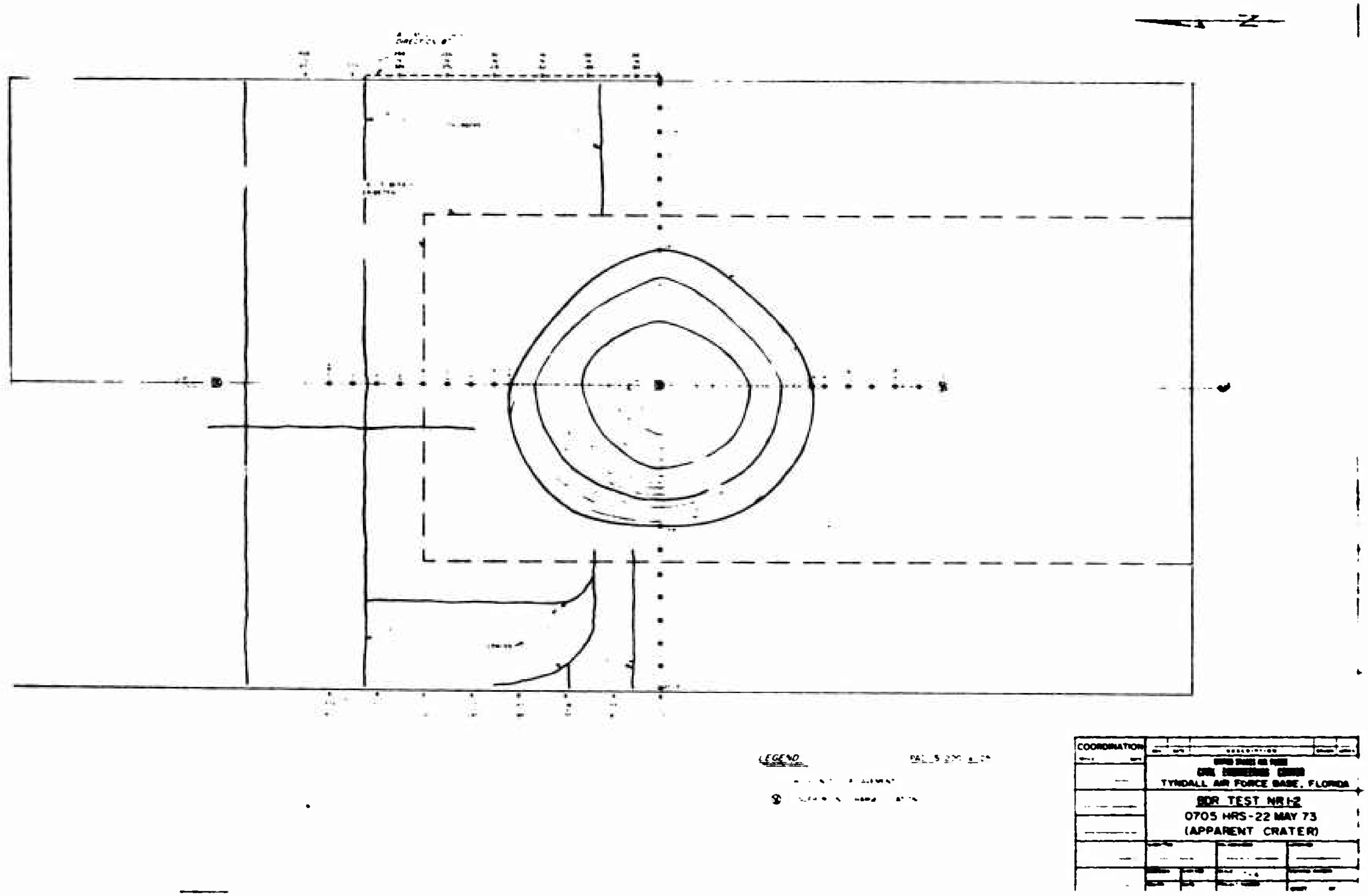


Figure 132. Apparent Crater Contours and Airfield Damage, Test 1-2

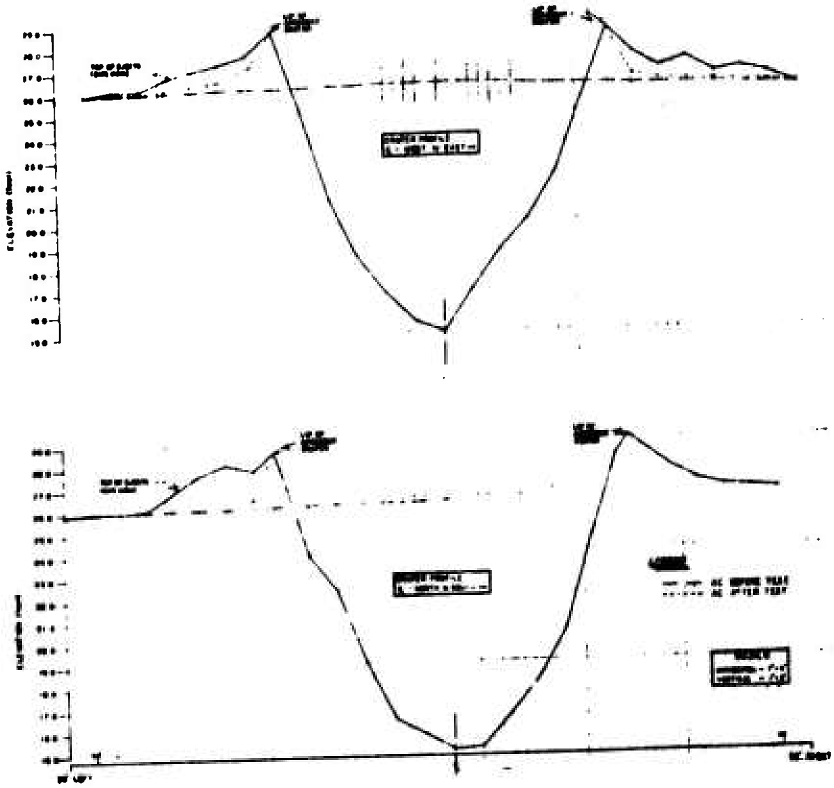


Figure 133. Crater Profiles, Test 1-2

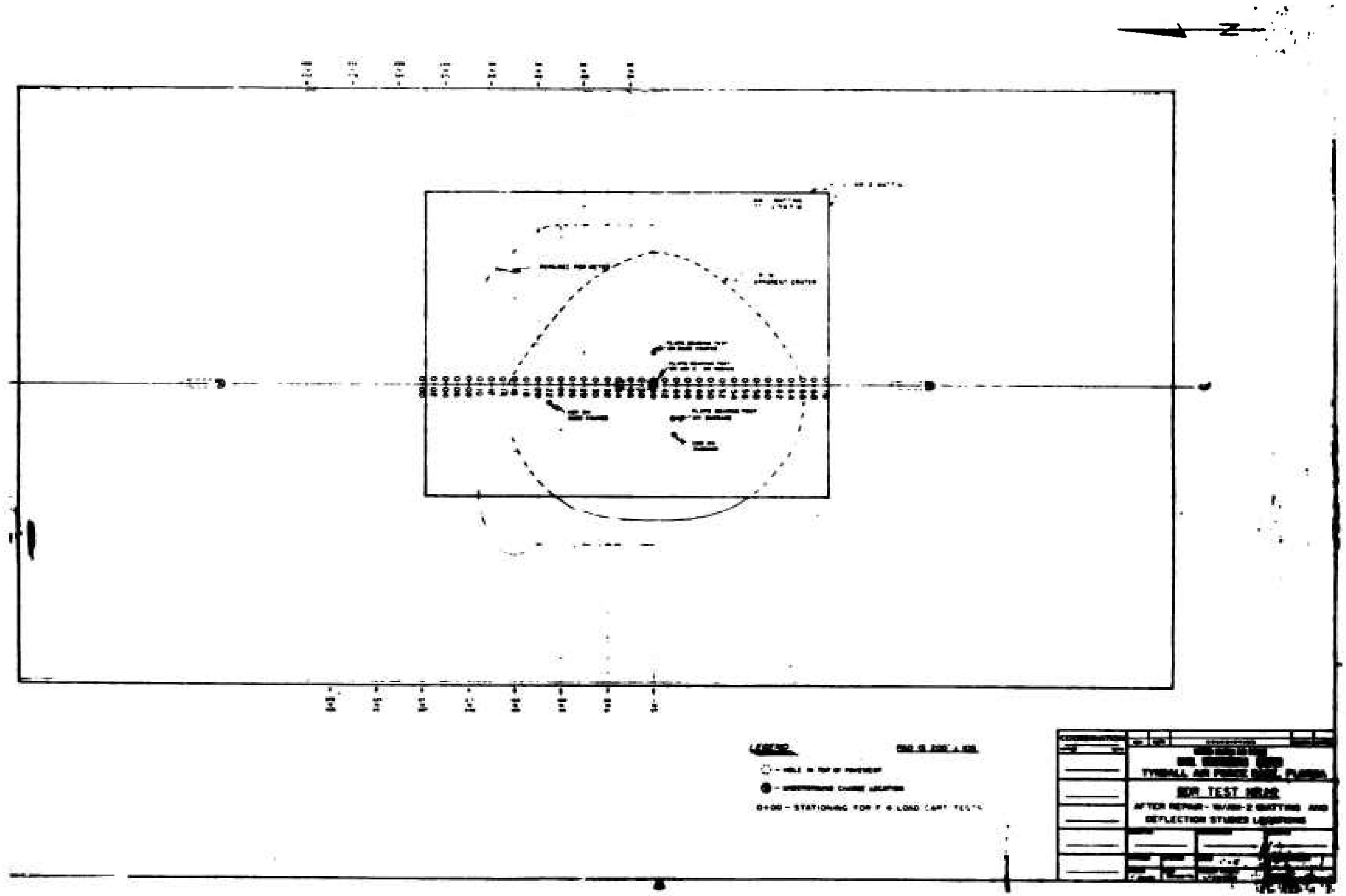


Figure 134. Plan View of the Repaired Perimeter, AM-2, Airfield Patch Placement and Stationing, Test 1-2

APPENDIX V

SITE AND TEST DRAWINGS, TEST 1-3

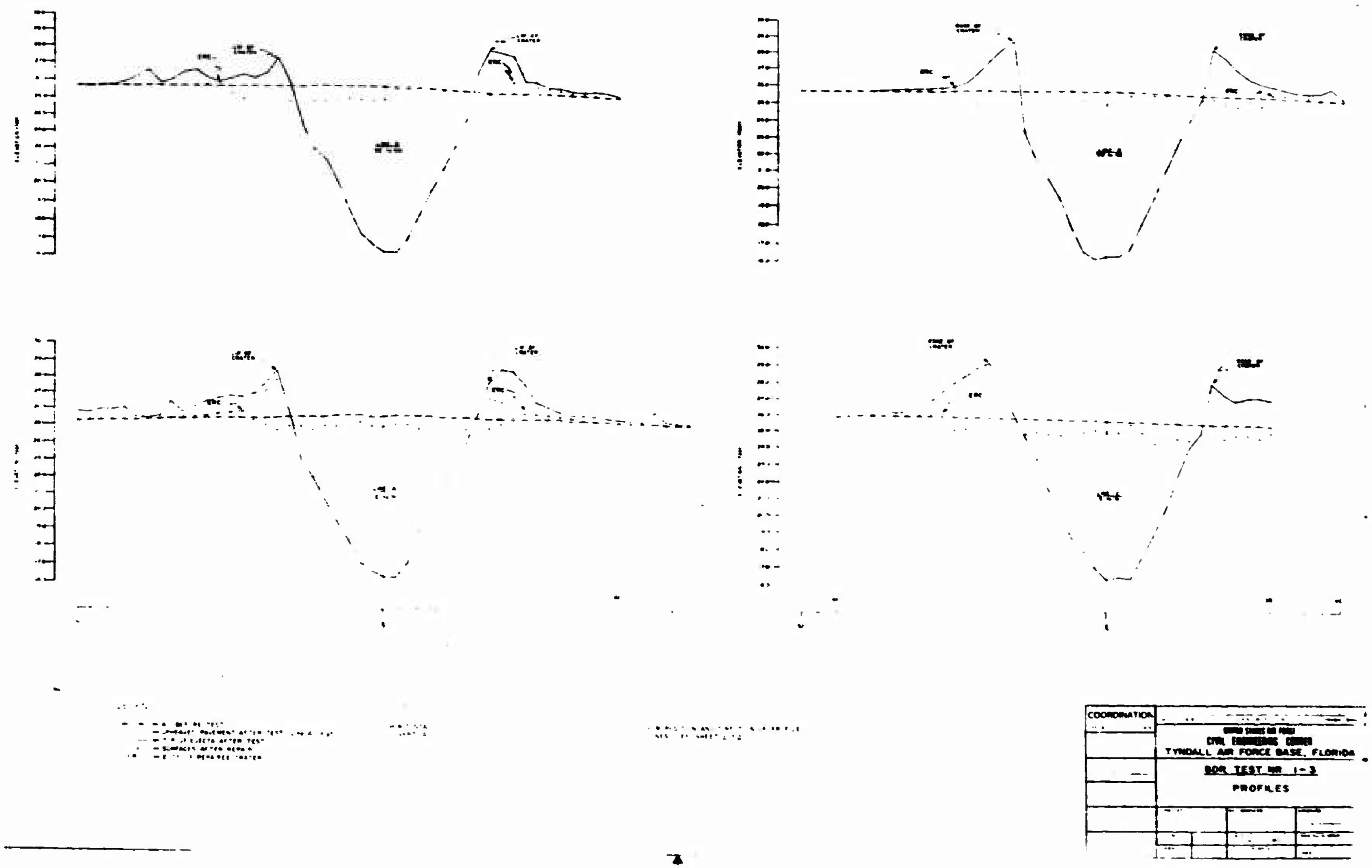


Figure 135. Crater Profiles and Cross Sections of Repaired and Original Pavement Surface, Test 1-3

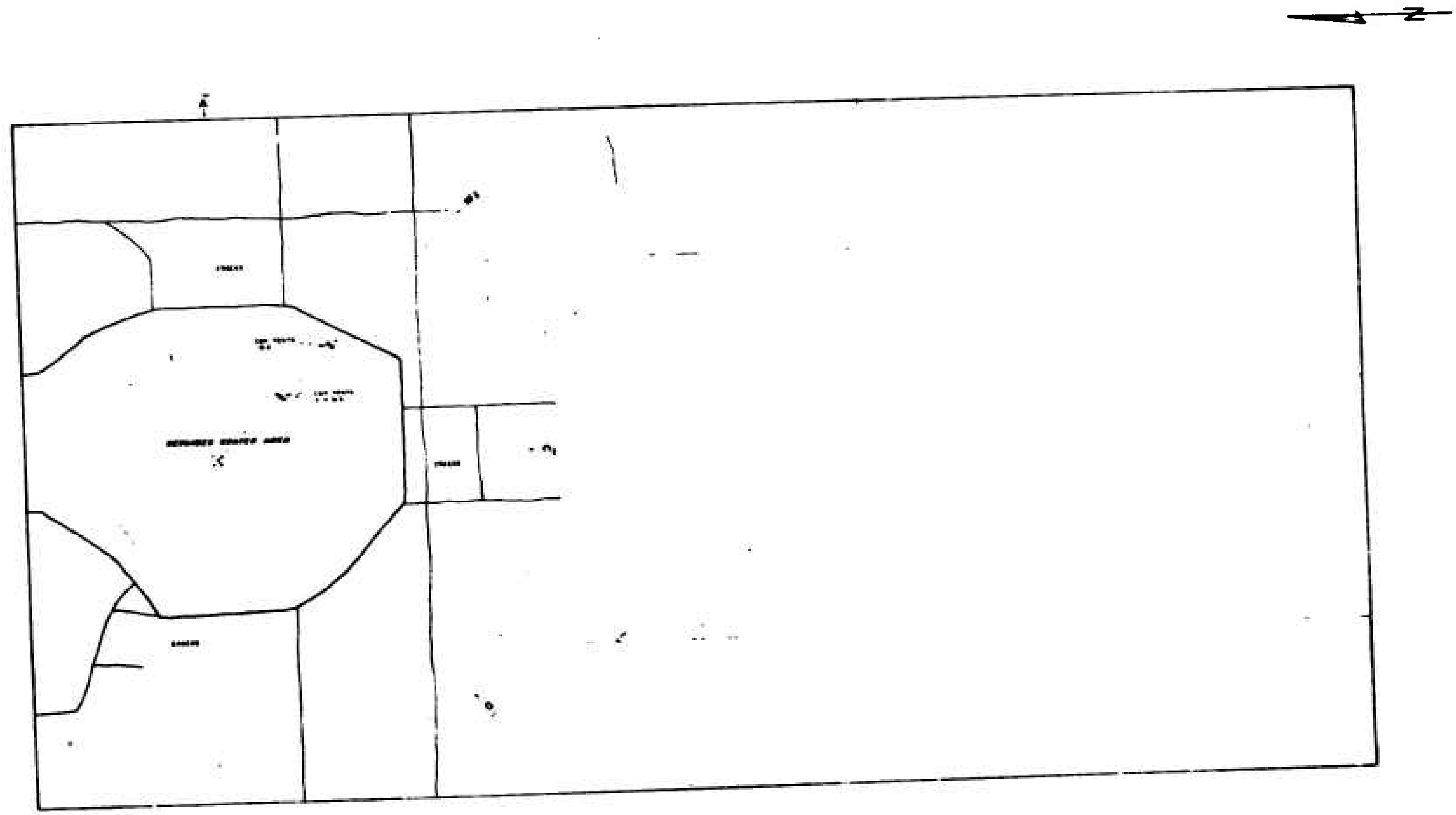


Figure 136. Plan View, Repaired Crater Perimeter, Pavement Damage and CBR Test Locations

APPENDIX VI

SITE AND TEST DRAWINGS, TEST 1-4

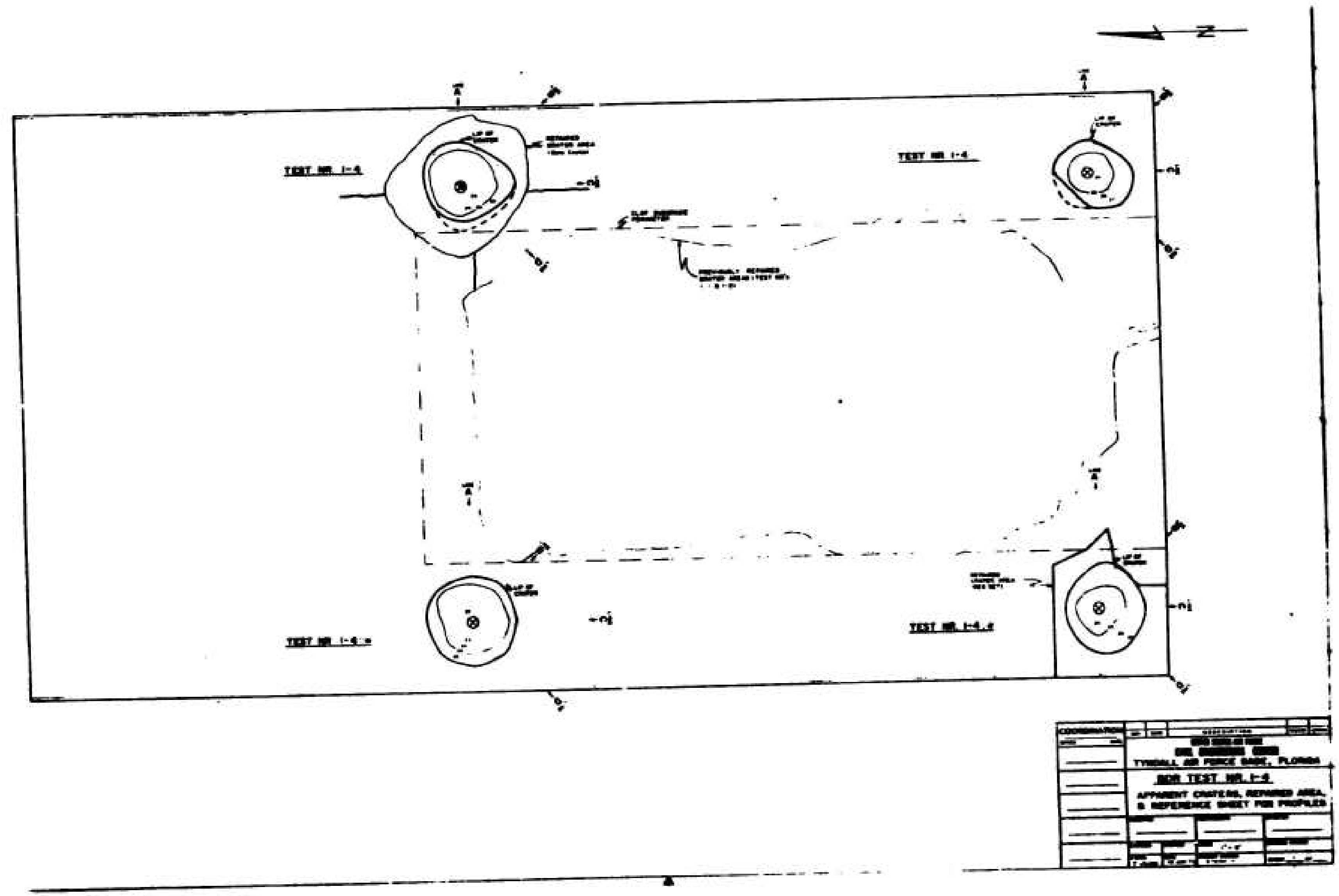


Figure 137. Plan View, Repaired Crater Perimeters, Crater Contours and Repair Locations, Test 1-4

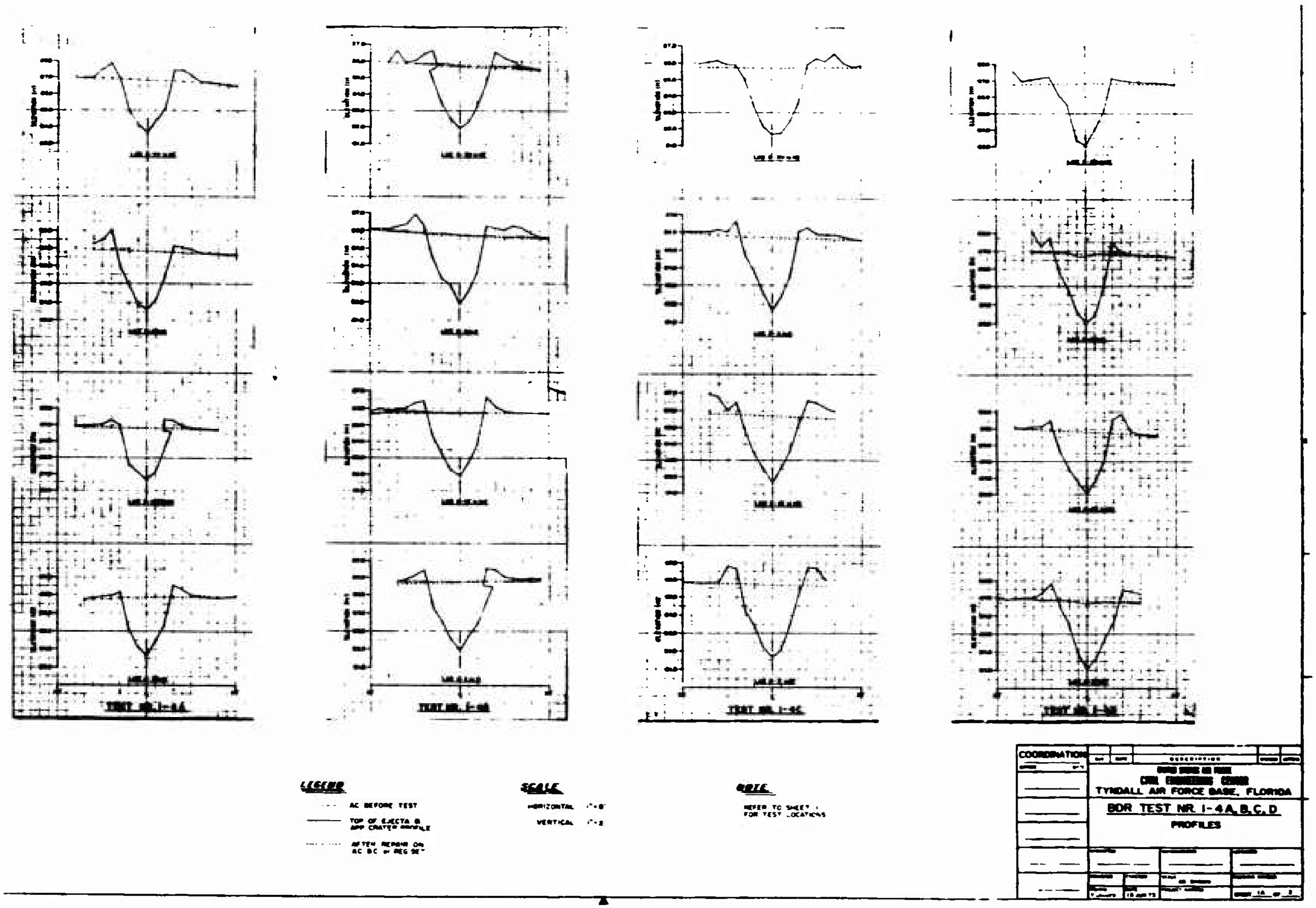


Figure 138. Crater Profiles and Cross Sections of Repaired and Original Pavement Surface, Test 1-4

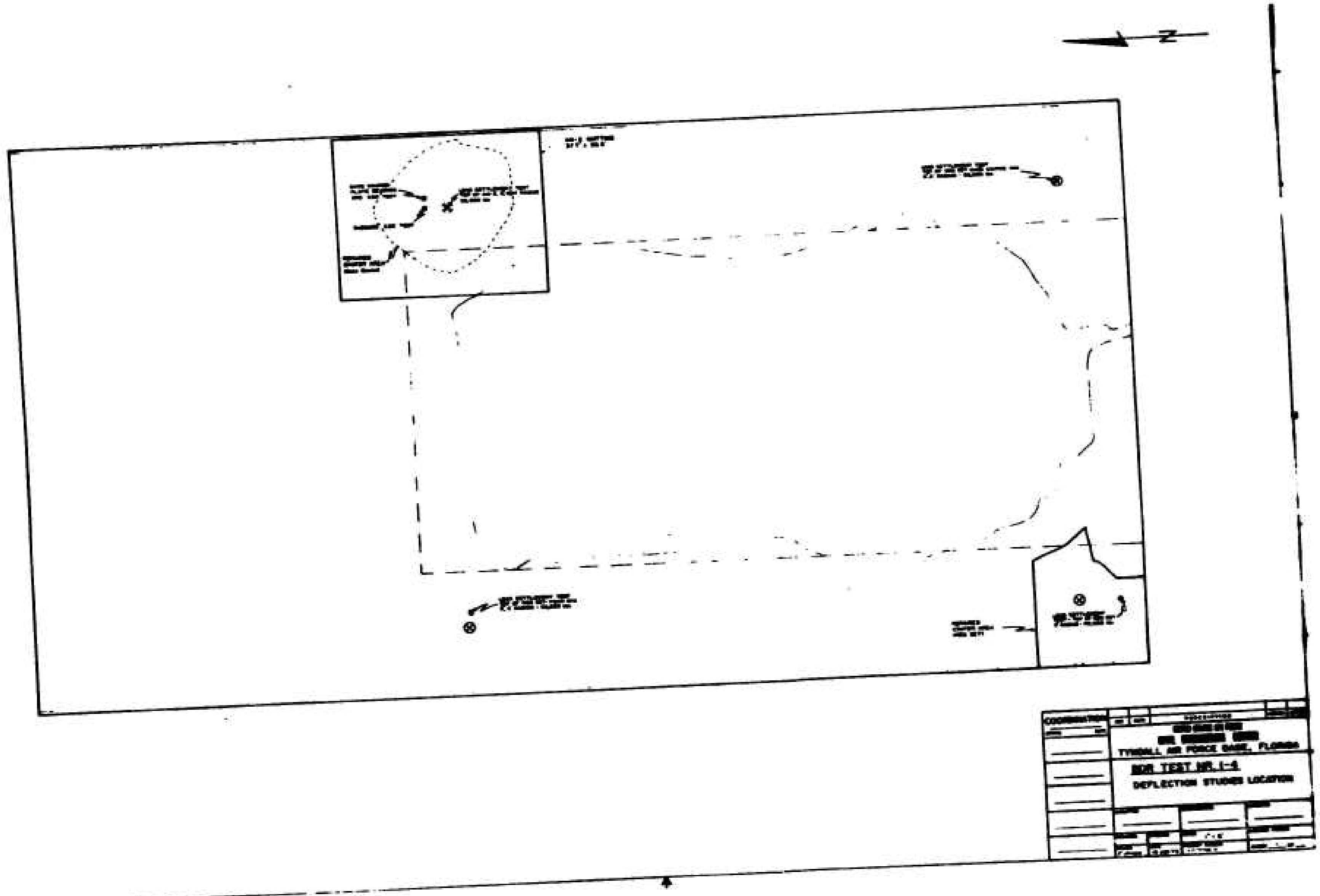


Figure 139. Deflection Study Locations, Test 1-4

APPENDIX VII

SITE AND TEST DRAWINGS, TEST 2-1

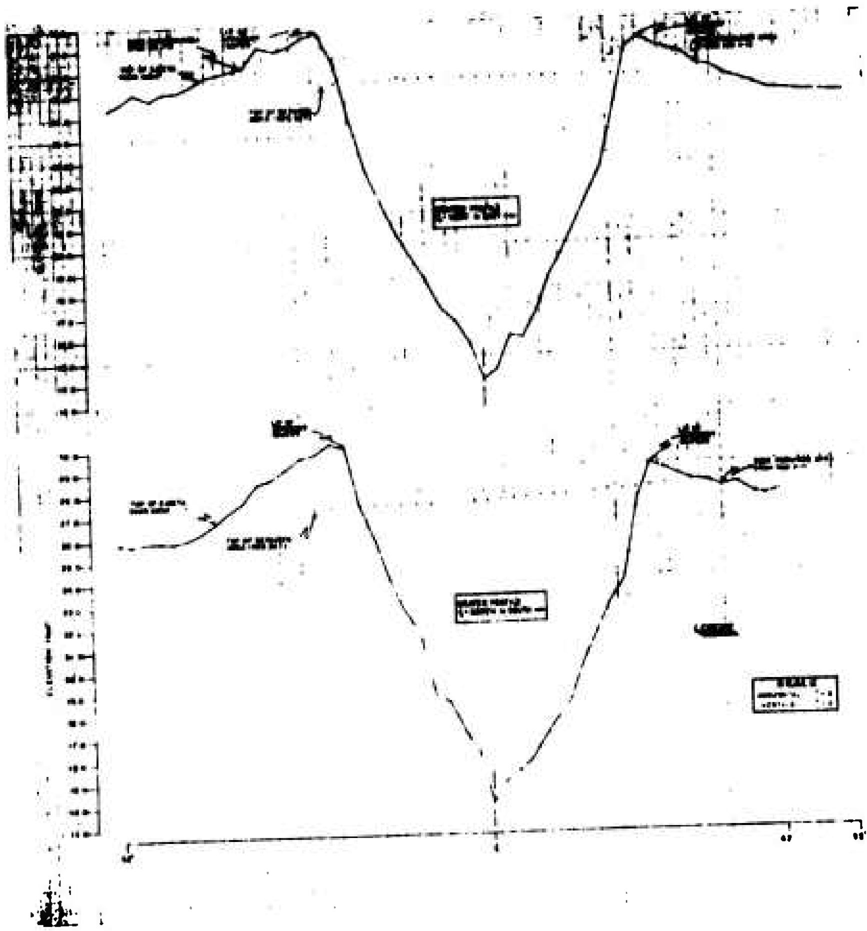


Figure 140. Crater Profiles, Test 2-1

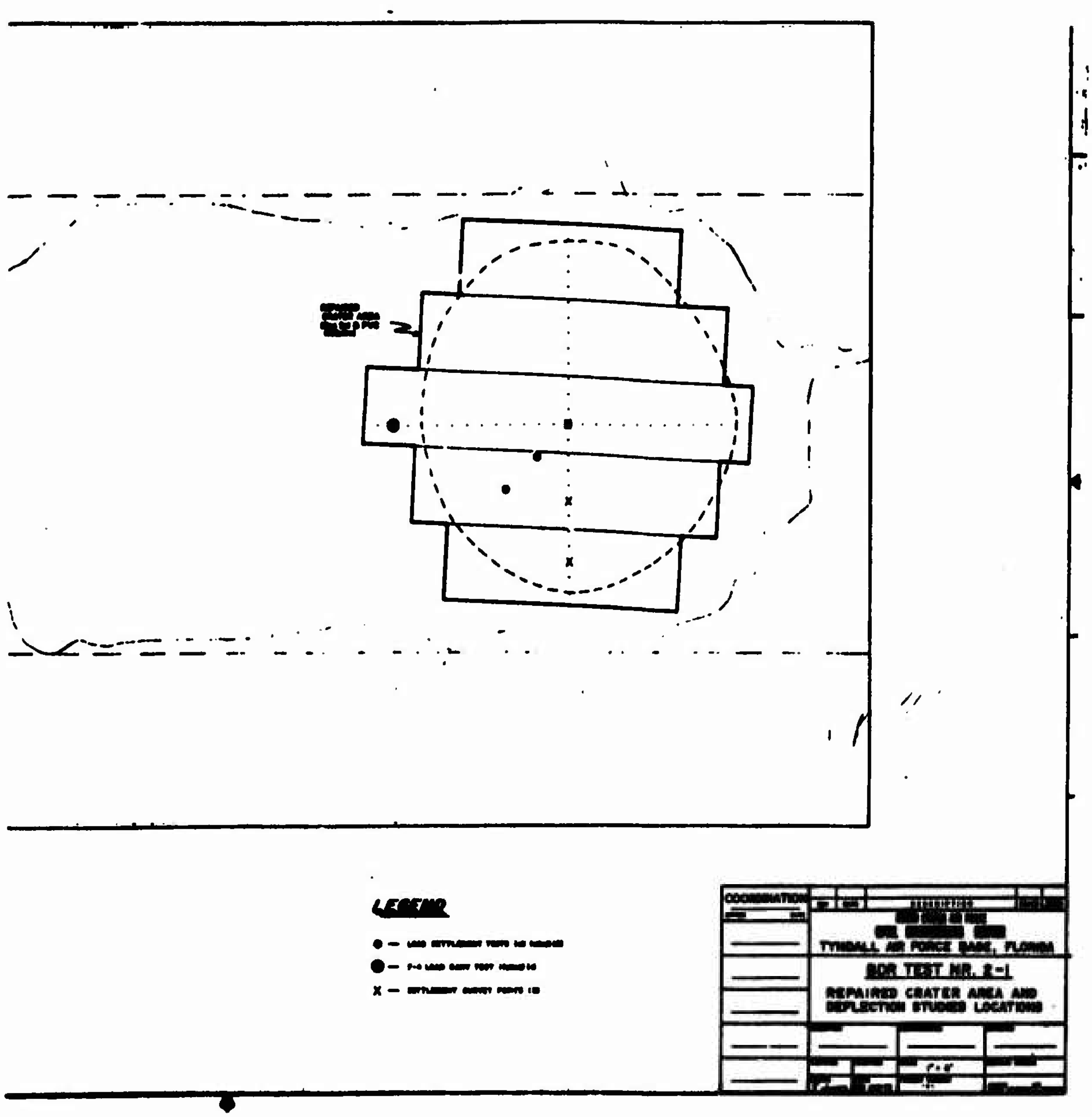


Figure 141. Plan View, Repaired Crater Area and Deflection Study Locations, Test 2-1

APPENDIX VIII

SPECIFICATION DATA, STRONG G-2 GYPSUM PUMP

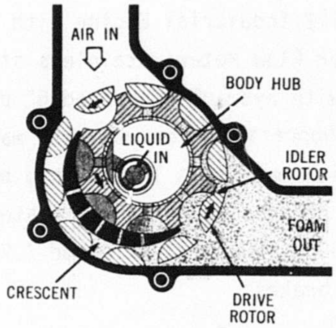
STRONG MANUFACTURING CO., INC.
GYPSUM PUMPS AS USED IN TEST 2-1:

<u>MODEL</u>

G-1 Equipped with Ford F-172 Industrial Engine with 4-speed Warner Transmission: 1½" Water Flow Meter: stainless steel mixing tub, 30" diameter X 24" high, with hydraulic powered 6" diameter feed auger and 2 stainless steel hoppers one for use with materials stored on ground, one for use with materials loaded into hopper from trucks: 2L10-0 pump with high production rotor and stator: all mounted on single axle trailer, 5000 pound per axle and 7.75 X 15" tires, electric or hydraulic brakes.

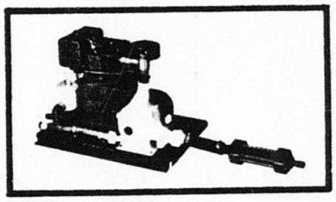
G-2 Equipped with Ford F-240 Industrial Engine with New Process 435 transmission; 1½" Water Flow Meter; stainless steel mixing tub, 30" diameter X 24" high with hydraulic driven feed auger: 2 stainless steel hoppers, one for use with materials stored on ground, one for use with materials loaded into the hopper from trucks: 2L10-0 pump with high production rotor and stator: all mounted on tandem axle trailer 3500 pound per axle and 7.75 X 15" tires, electric or hydraulic brakes.

APPENDIX IX
SPECIFICATION DATA, WAUKESHA FOAMING UNIT



The Waukesha foam generator takes air from the atmosphere and mixes it with a metered amount of foamable liquid. Foam is produced in less than one revolution of the mixing pump rotor and is directed out of the generator through a hose or conduit. It operates at 1600-2500 rpm. The foaming liquid consumption is from 5-6 gal/min to give foam output of from 100-120 gal/min.

Normal pumping distance is 20 ft. using a 1¼" hose. Longer distances are possible with a larger diameter hose.



MODEL C-620-8
Foam Generator with engine

MODEL C-620
Foam Generator without engine

Foam is generated as a feed pump injects the liquid into the air handling section on the unit. Liquid enters the foam-chamber through an opening in the drive shaft and passes through tiny openings in the idler rotor. The fast-moving motor elements churn the air and liquid mixture into foam and pump the bubbly mass out through a foam conditioner.

APPENDIX X
SPECIFICATION DATA, SELECT BDR EQUIPMENT

280RT DOZER AND AC745 LOADER

Manufacturer	Michigan	Allis-Chalmer
Model	280RT	AC745
Horse Power Governed	318 HP	240 HP
Weight	52,500 lbs (without dozer)	35,250 lbs (without bucket)
Length	276 in. (without dozer)	293 in. (with bucket)
Width	160 in.	115 in. (with bucket)
Height	144 in.	110 in.
Tire Size	29.5 - 25	23.5 - 25
Bucket	****	3½ Yd. Multi-Purpose
Tipping Load	****	0^{o} 26,200 lb 30^{o} 24,000 lb 35^{o} 23,200 lb 40^{o} 22,300 lb 45^{o} 21,400 lb
Turn Radius	****	17 ft 9 in
Breakout Force	****	41,500 lb

APPENDIX XI
DYNAMIC PAVEMENT SYSTEM TESTING, TEST 1-2

EXISTING PAVEMENT

LAYER 1	$E_1 = 2.5 \times 10^6$ PSI	$V_1 = 0.2$
LAYER 2	$E_2 = 0.26 \times 10^6$ PSI	$V_2 = 0.3$
LAYER 3*	$E_3 = 56{,}000$ PSI	$V_3 = 0.4$

ON BACKFILL *

$E_B = 22{,}000$ PSI $\quad V_B = 0.4$

ON GRAVEL

$E_G = 47{,}000$ PSI $\quad V_G = 0.3$

* FOR LARGE STRAINS, THE THIRD LAYER PROPERTY AND BACKFILL E-VALUE MAY BE DIVIDED BY 5. THIS WOULD TEND TO SHOW BETTER AGREEMENT BETWEEN THE MEASURED AND COMPUTED DISPLACEMENT CLOSE TO LOADED AREA.

Figure 142. Recommended Parameters for BDR Studies

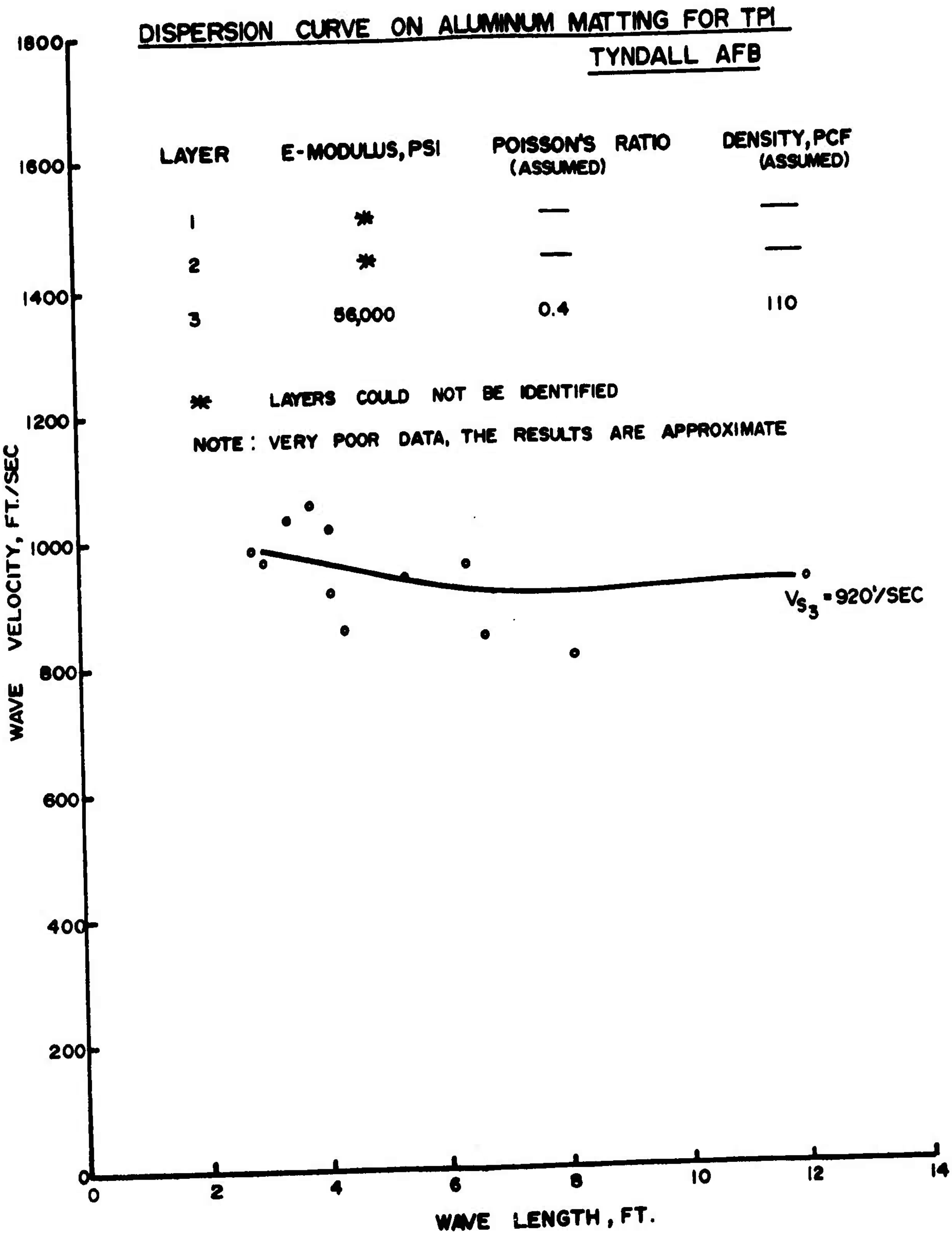
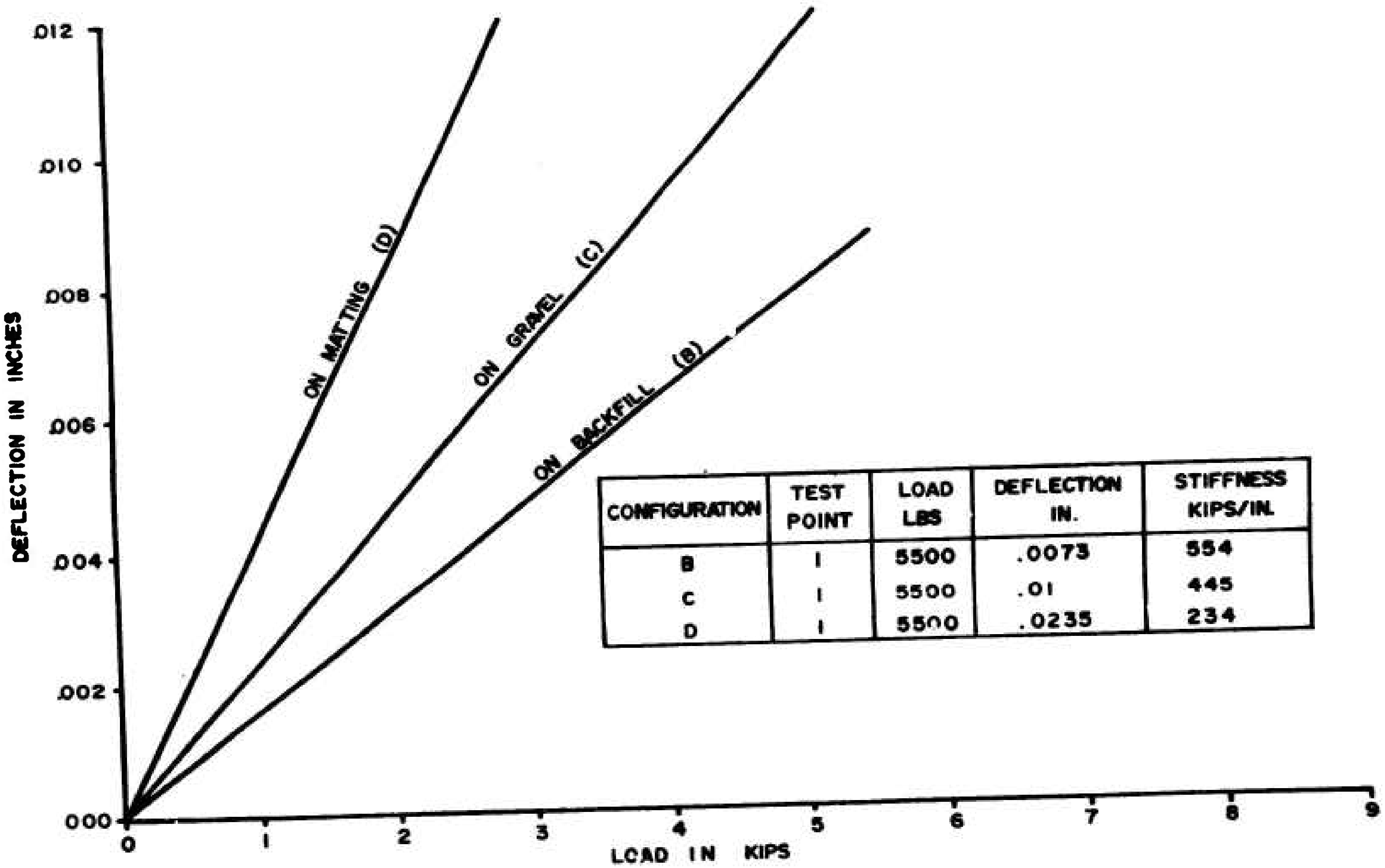
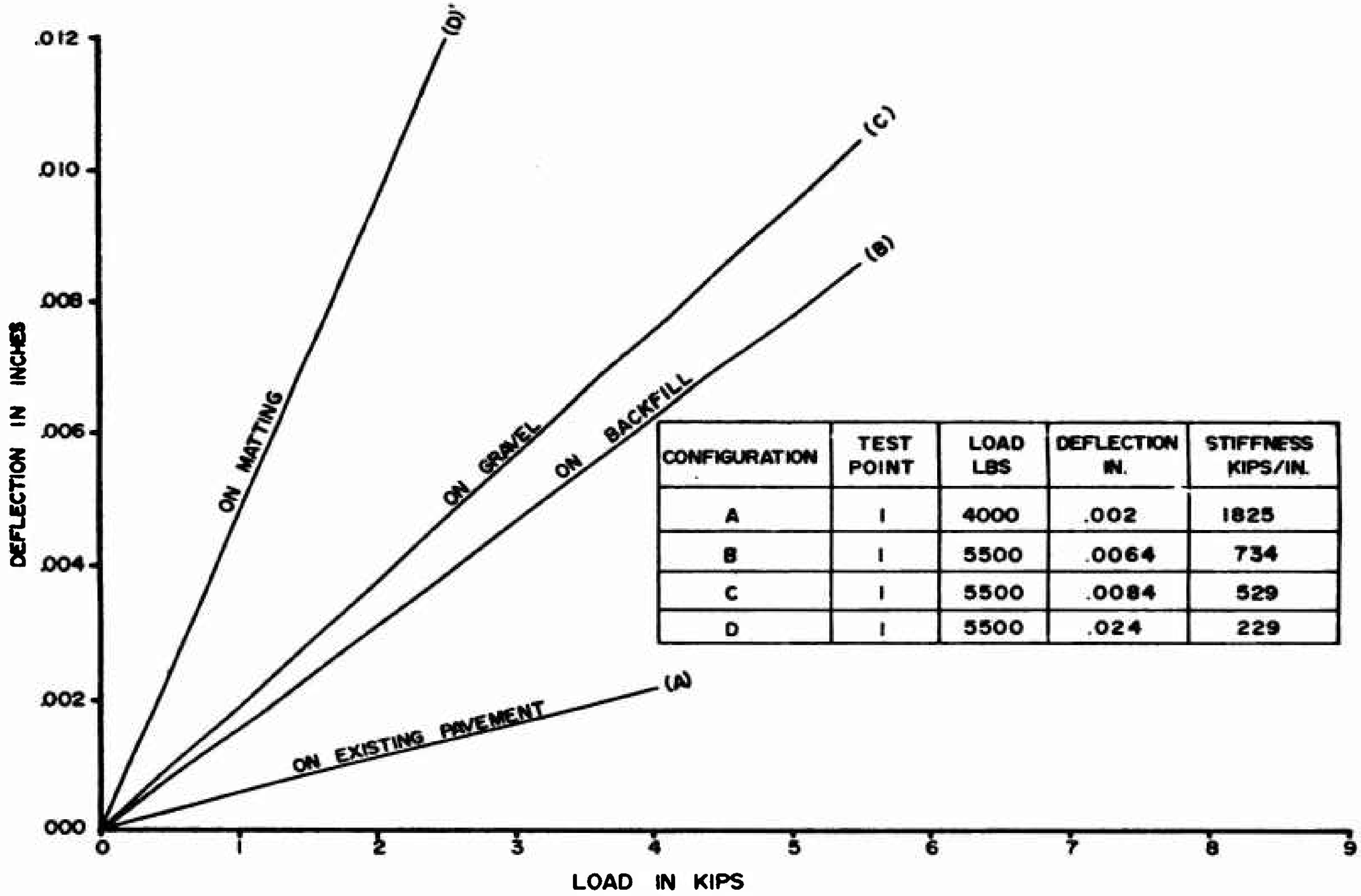


Figure 143. Dispersion Curve on Aluminum Matting for TPI Tyndall AFB



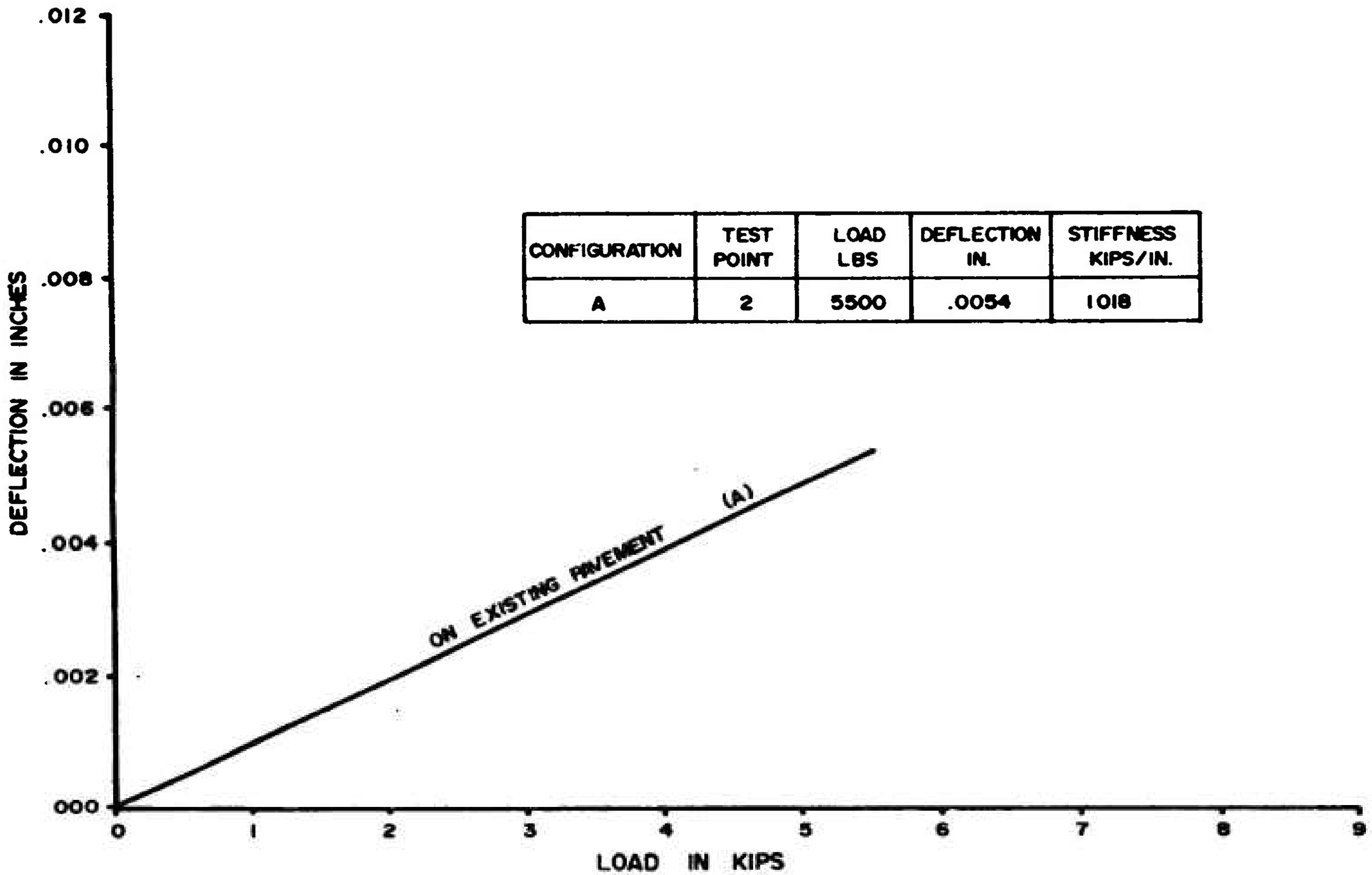
CONFIGURATION	TEST POINT	LOAD LBS	DEFLECTION IN.	STIFFNESS KIPS/IN.
B	I	5500	.0073	554
C	I	5500	.01	445
D	I	5500	.0235	234

Figure 144. Load Deflection Curves at TPI, 15 HZ-Tyndall AFB



CONFIGURATION	TEST POINT	LOAD LBS	DEFLECTION IN.	STIFFNESS KIPS/IN.
A	I	4000	.002	1825
B	I	5500	.0064	734
C	I	5500	.0084	529
D	I	5500	.024	229

Figure 145. Load Deflection Curves at TPI, 25HZ-Tyndall AFB



CONFIGURATION	TEST POINT	LOAD LBS	DEFLECTION IN.	STIFFNESS KIPS/IN.
A	2	5500	.0054	1018

Figure 146. Load Deflection Curve at TP2, 15 HZ, Tyndall AFB

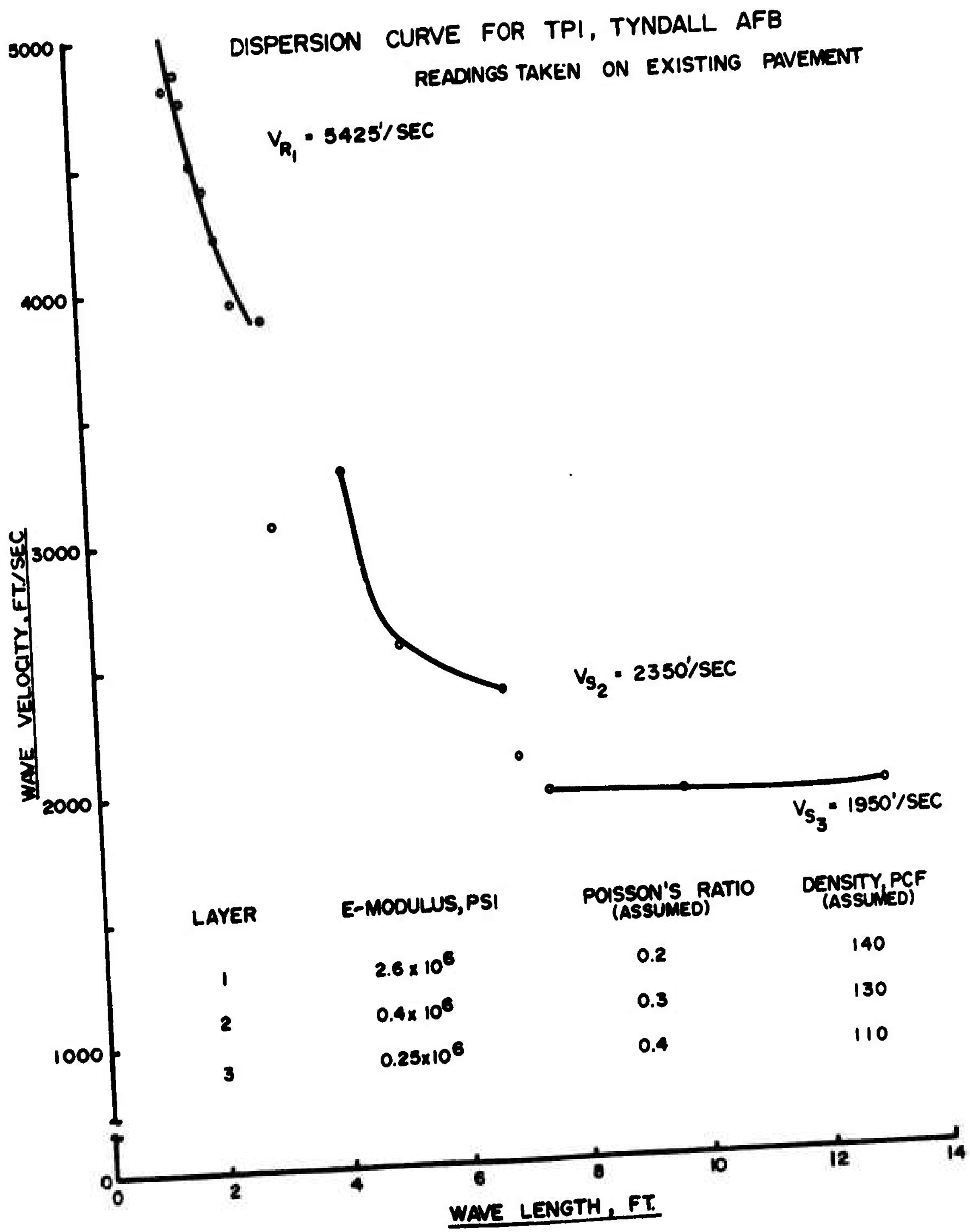


Figure 147. Dispersion Curve for TPI, Tyndall AFB

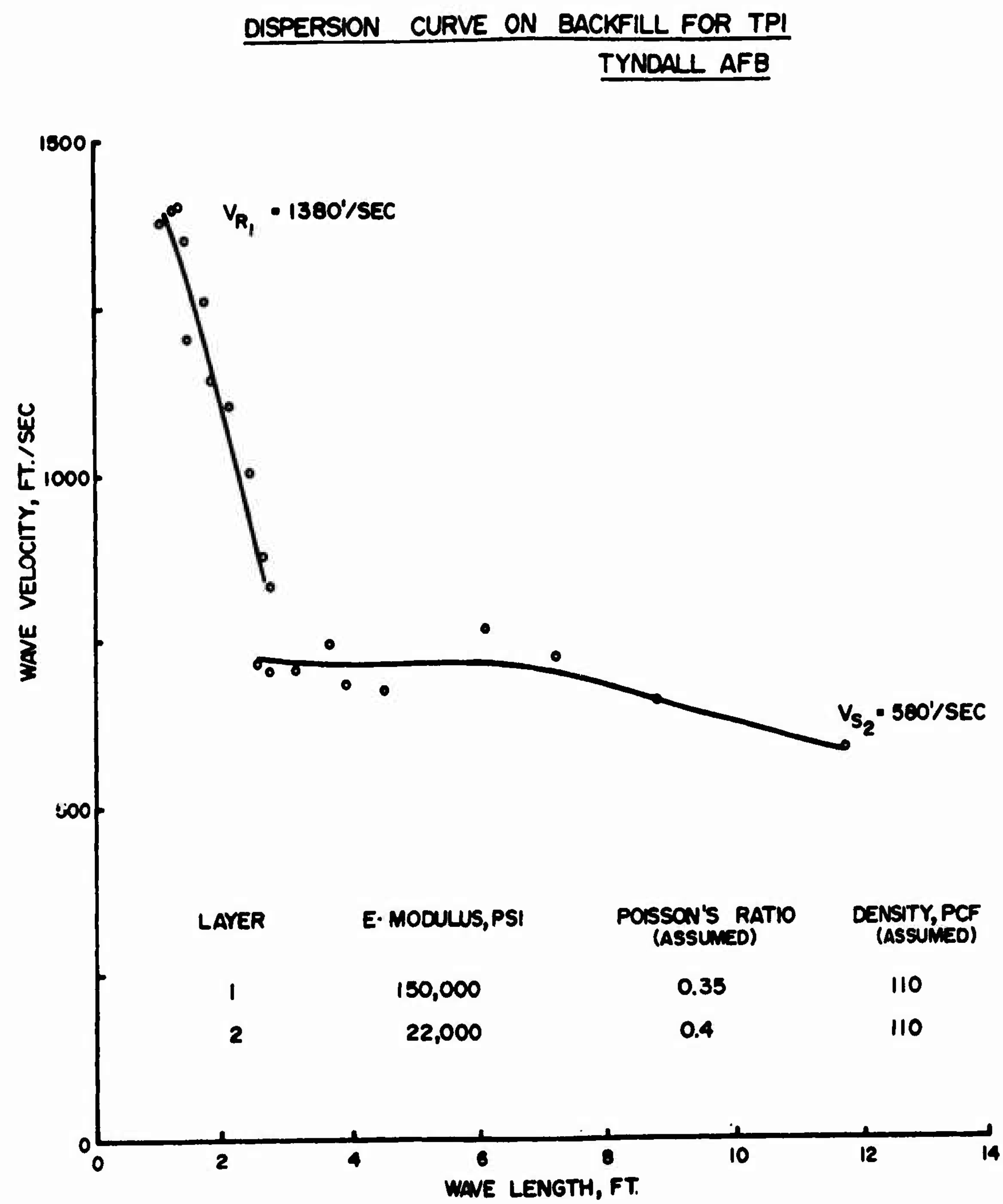


Figure 148. Dispersion Curve on Backfill for TPI Tyndall AFB

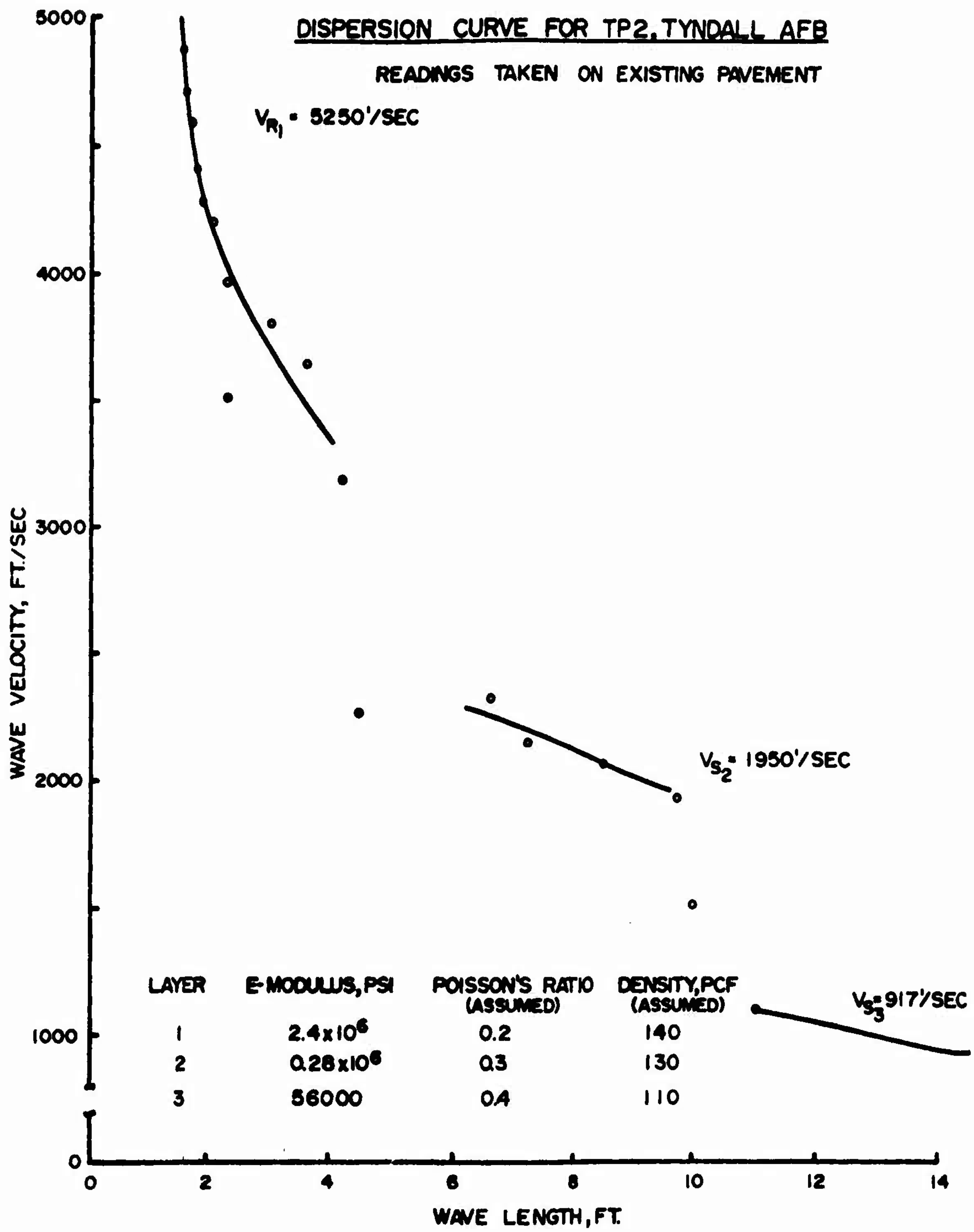


Figure 149. Dispersion Curve for TP2, Tyndall AFB

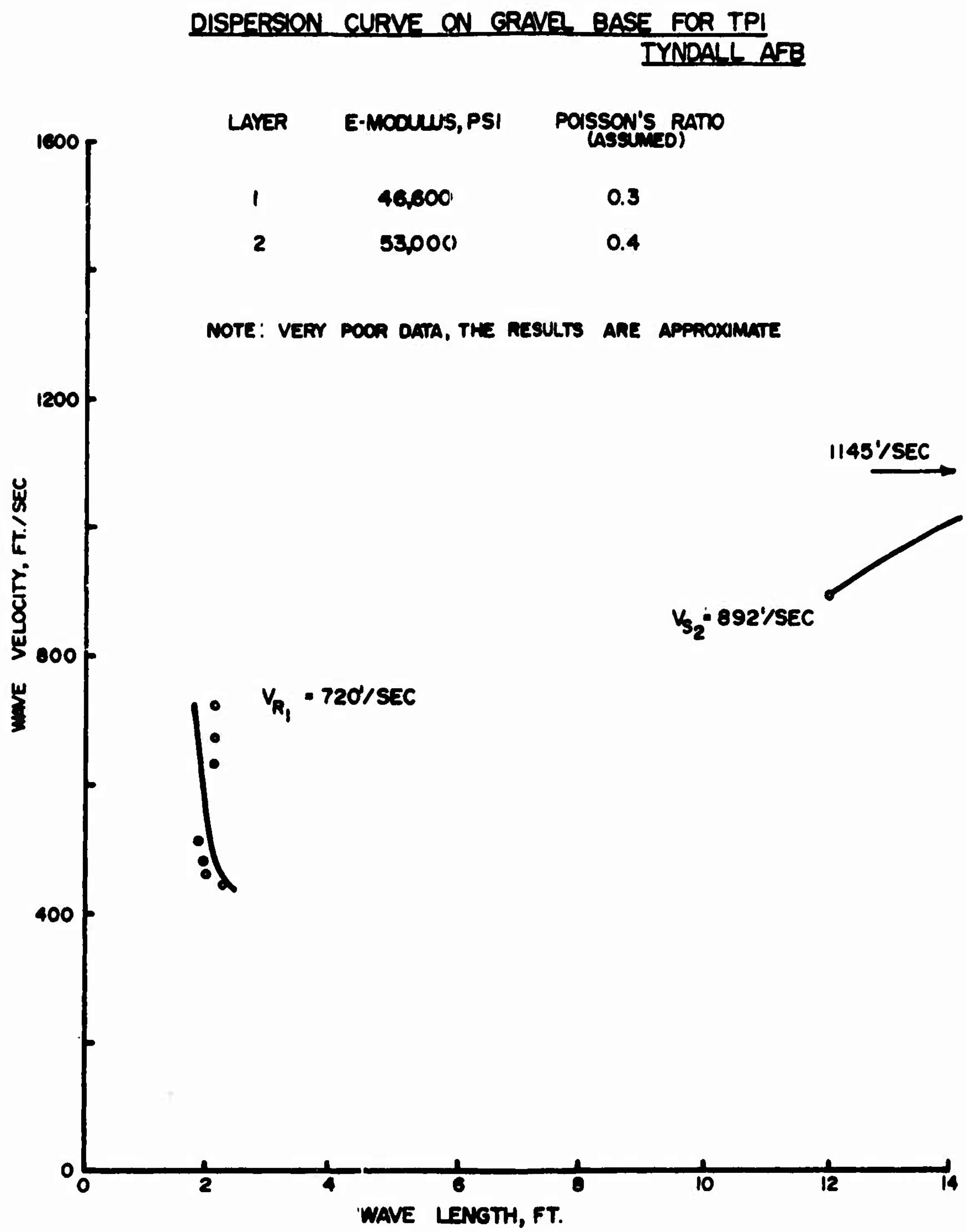
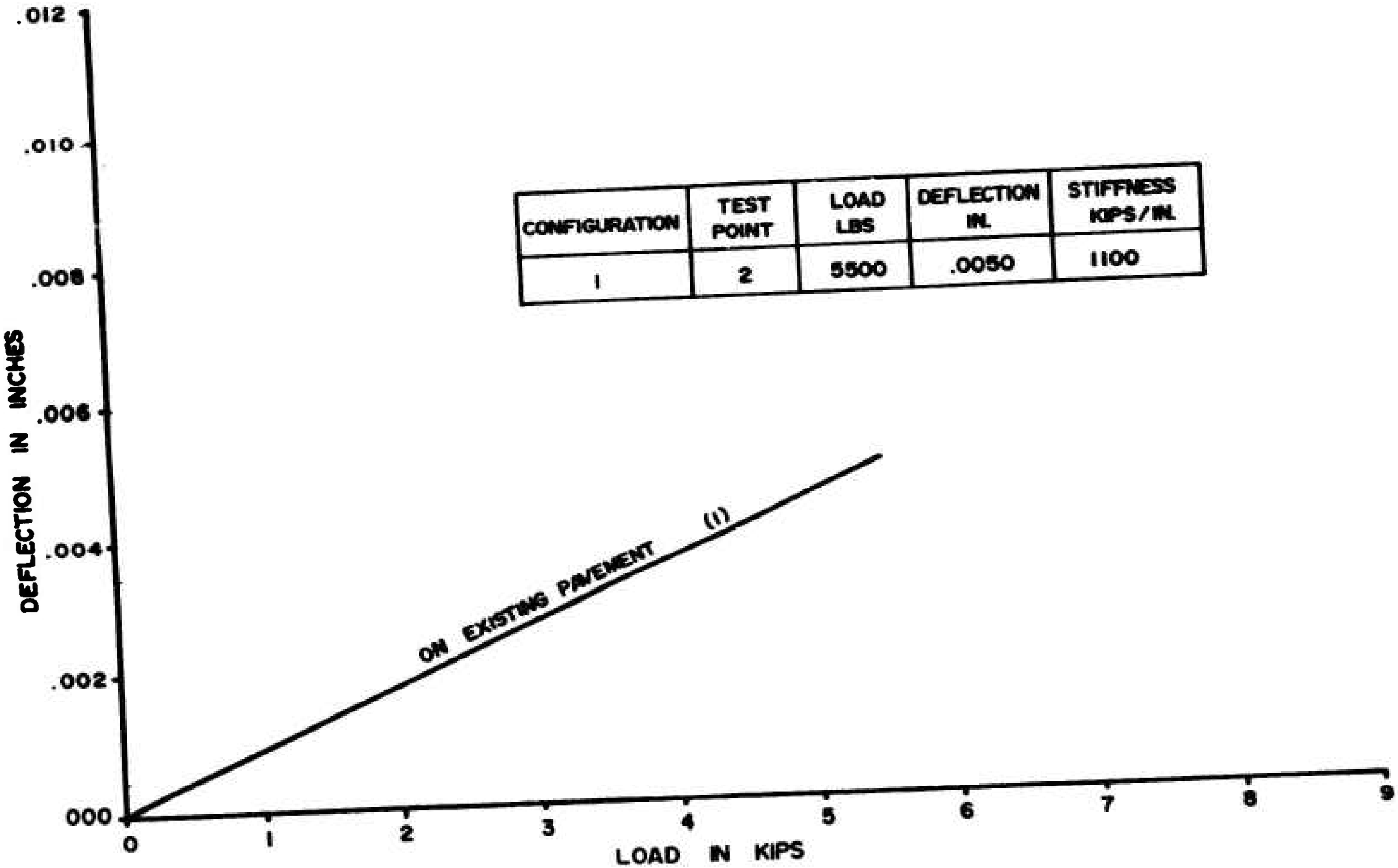


Figure 150. Dispersion Curve on Gravel Base for TPI, Tyndall AFB



CONFIGURATION	TEST POINT	LOAD LBS	DEFLECTION IN.	STIFFNESS KIPS/IN.
1	2	5500	.0050	1100

Figure 151. Load Deflection Curves at TP2, 25HZ, Tyndall AFB

APPENDIX XII
PROPERTIES OF REGULATED-SET CEMENT

Generally concretes made from Regulated Set Cements exhibit properties very similar to concretes made with Portland cements. The major differences between the concretes being the time of set and strength gain. Concrete made with Regulated Set Cements usually sets in ten to thirty minutes and has appreciable strength in one to six hours. The strength gaining properties of Regulated Set Concrete like those of normal Portland cements concrete continue through and beyond one year.

Chemically, Regulated Set Cement is very similar to normal Portland cements with both containing Calcium Silicates, Calcium Alumina Ferrites and Calcium Sulfates. The diference being in the Calcium Aluminate phases.

Specific properties of concrete made with Regulated Set Cements are commented on and depicted by the attached graphs.

Effect of Temperatures: Concretes made from Regulated Set Cements are extremely temperature sensitive. Changes in temperatures effect setting times, strengths and volume changes. As shown by sheet number 3 a concrete with performs satisfactorily at $73^{o}F$ will not set up at $52^{o}F$ until after one day and has short working time (five to seven minutes) at $90^{o}F$. A result of this temperature sensitivity, close control of concrete temperatures is required when working with Regulated Set Cement concretes.

Regulated Set Cement can be formulated to produce concretes at low temperatures (30 to $40^{o}F$) or high temperatures (90 to $100^{o}F$), but a combination cement (one suitable for both) has not been developed unless retarders are used with the low temperature formulation.

Volume Changes: RS-2 Experimental Regulated Set Cement has shrinkage values in excess of either Type I or Type III cements. This can be reduced by modifying the formulation of the cement without undue sacrifice of compressive strengths. Regulated Set Cement produced for marketing would exhibit drying shrinkage characteristics similar to Type I and Type III cements.

Concretes made using Regulated Set Cements over retarded by low

temperatures (no strength gain in 24 hours) exhibit this problem.

Strength: Concretes made from Regulated Set Cements develops appreciable strength at from one to three hours depending on temperatures and formulations.

The strengths continue to increase through one year similar to normal Portland cements. We expect the strength gain to continue after one year as it does with normal Portland cements.

Sulfate Resistance and Chemical Attack: Concretes made with Regulated Set Cements do not exhibit appreciable resistance to sulfate attack. In this area it is similar to a high C_3A Portland cement. Resistance to attacks by other chemicals should be similar to high C_3A Portland cements.

With proper curing the surface of concretes made with Regulated Set Cements is comparable to the surface of concrete made with normal Portland cement.

Retarders and Working Time: Most widely used retarders for normal Portland cements are not effective for Regulated Set Cements. To retard Regulated Set Cement special retarders are required such as citric acid.

The addition rate of the retarder has to be closely controlled in order not to sacrifice the early strengths. The dosage rate will depend on Regulated Set Cement formulation and concrete temperatures.

An effective retarder would be concrete temperature if it is closely controlled.

The actual retarder and dosage should be checked on the concrete being produced at the specified concrete temperature to be effective.

Retarding the set longer than thirty minutes at normal temperatures is not generally advisable since early strengths are sacrificed. At elevated temperatures the set can usually only be retarded to twenty minutes.

Regulated Set Cement concretes generally set up in ten to thirty minutes. Loss in workability (slump loss) begins immediately with the addition of water. In most cases the concrete must be in place and consolidated in twenty to twenty-five minutes and can be finished in thirty to forty-five minutes. By working time and time of set we are referring to the time the concrete must be in place and consolidated.

SERIES 205 - REGULATED SET CEMENT
JUNE 1970 PRODUCTION REG. SET II
(T-306)

STANDARD PHYSICAL TESTS

(ASTM C-150)

325	90.1
Wagner	2800
Blaine	5800
Specific Gravity	3.08
N.C.	25.0
Gilmore: Initial	0:10
Final	0:17
Vicat Set	10 Min.
% Auto. Exp	0.080
% Air	14.5
% Water	50.0
Flow	101

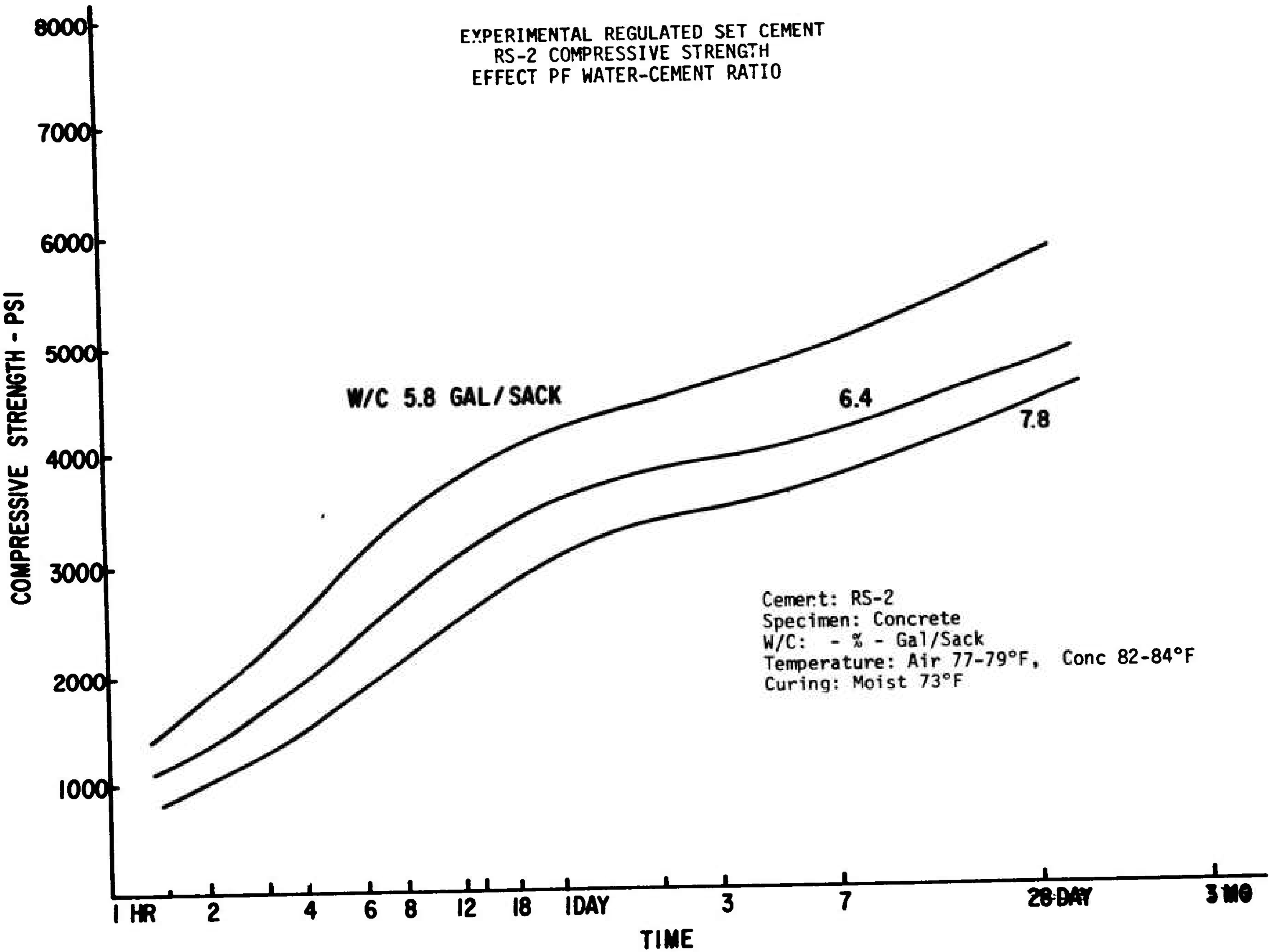
Compressive Strength, psi

1 Day	3800
3 Days	4610
7 Days	4830
28 Days	5790
3 Mos.	6550
6 Mos.	7380
1 Year	7510

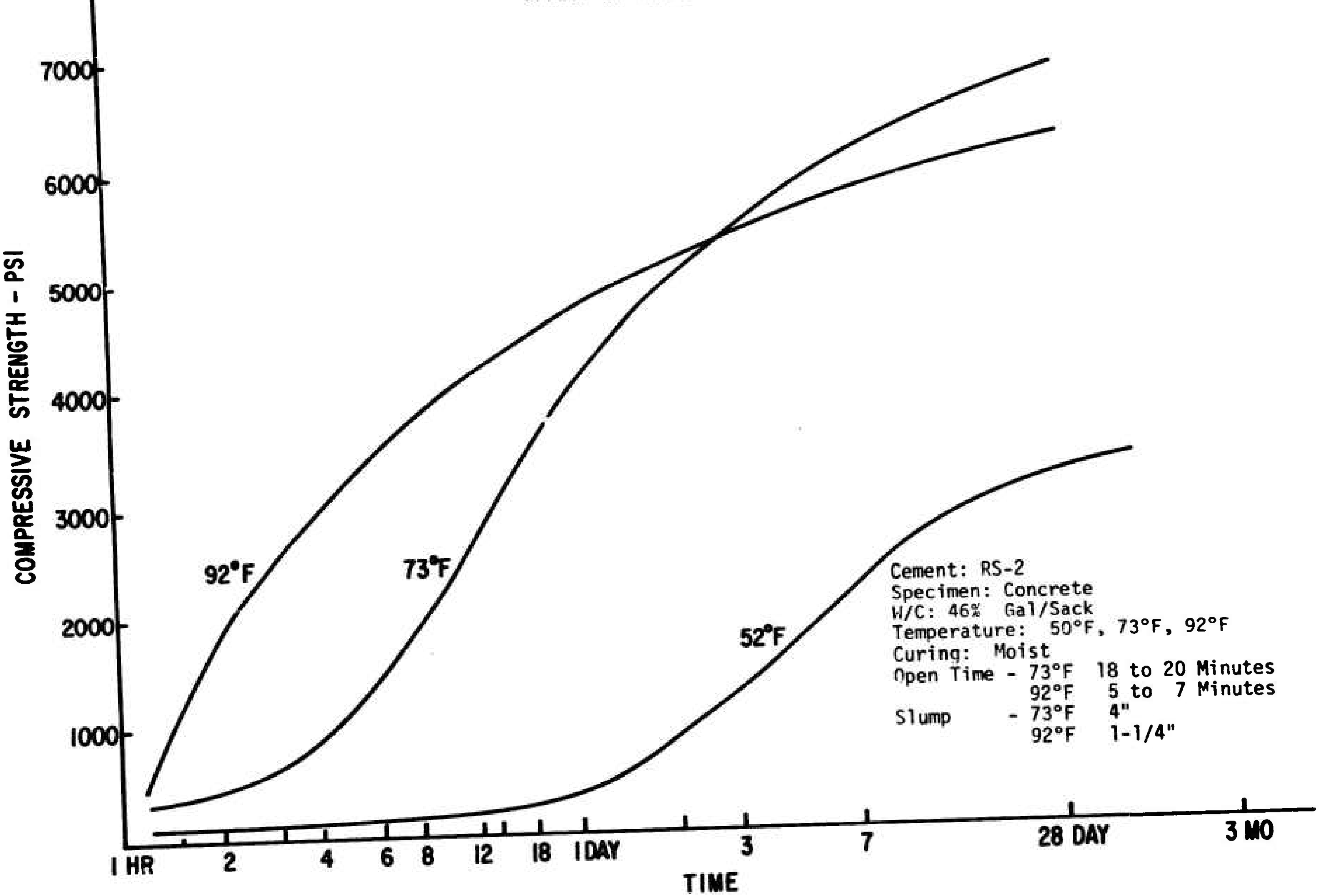
Tensile Strength, psi

1 Day	510
3 Days	575
7 Days	585
28 Days	620
3 Mos.	720
6 Mos.	720
1 Year	740

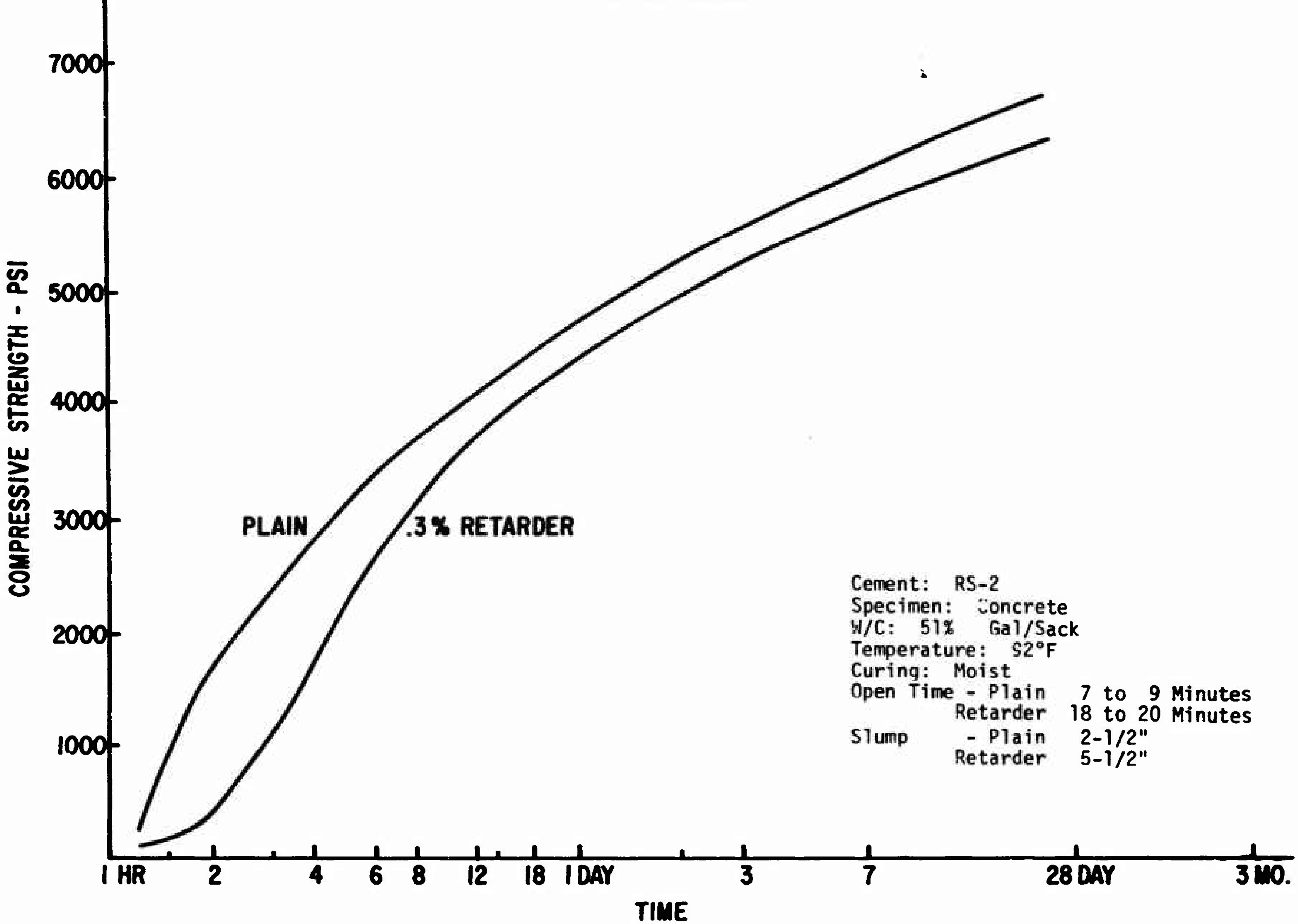
NOTE: All tests in duplicate.

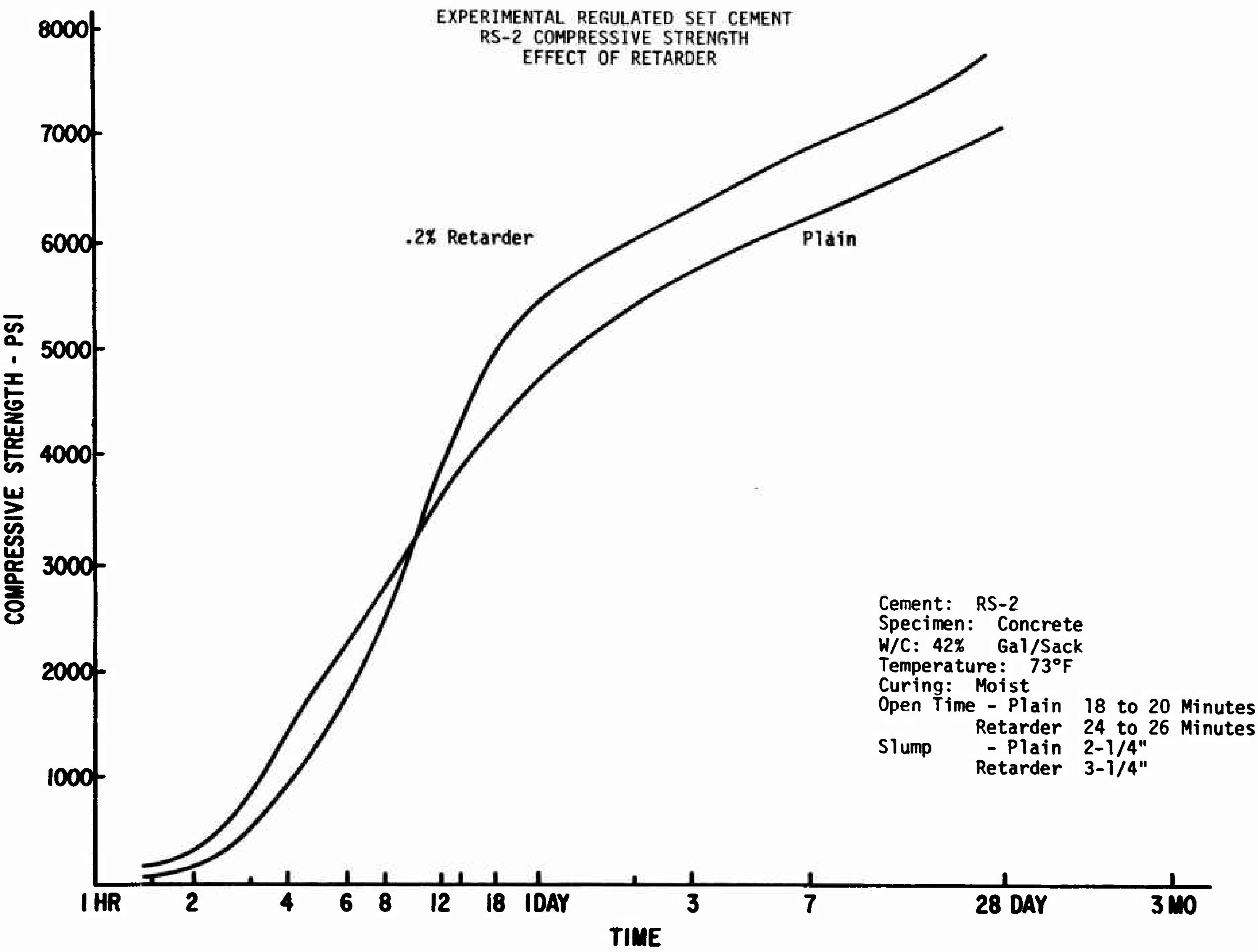

EXPERIMENTAL REGULATED SET CEMENT
RS-2 COMPRESSIVE STRENGTH
EFFECT PF WATER-CEMENT RATIO
COMPRESSIVE STRENGTH - PSI
8000
7000
6000
5000
4000
3000
2000
1000
W/C 5.8 GAL/SACK
6.4
7.8
Cement: RS-2
Specimen: Concrete
W/C: - % - Gal/Sack
Temperature: Air 77-79°F, Conc 82-84°F
Curing: Moist 73°F
1 HR
2
4
6
8
12
18
1DAY
3
7
28 DAY
3 MO
TIME

EXPERIMENTAL REGULATED SET CEMENT
RS-2 COMPRESSIVE STRENGTH
EFFECT OF TEMPERATURE

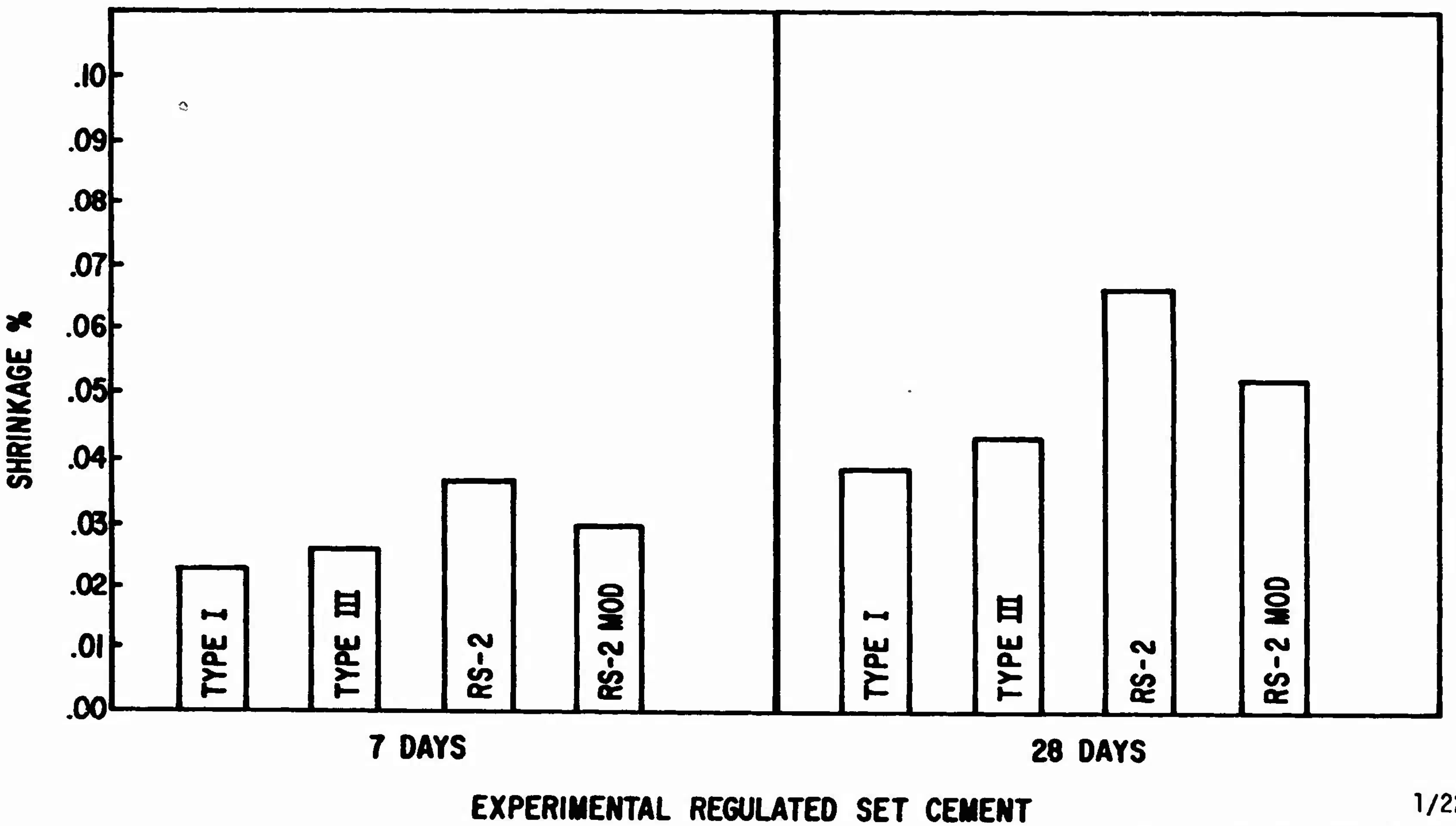


EXPERIMENTAL REGULATED SET CEMENT
RS-2 COMPRESSIVE STRENGTH
EFFECT OF RETARDER

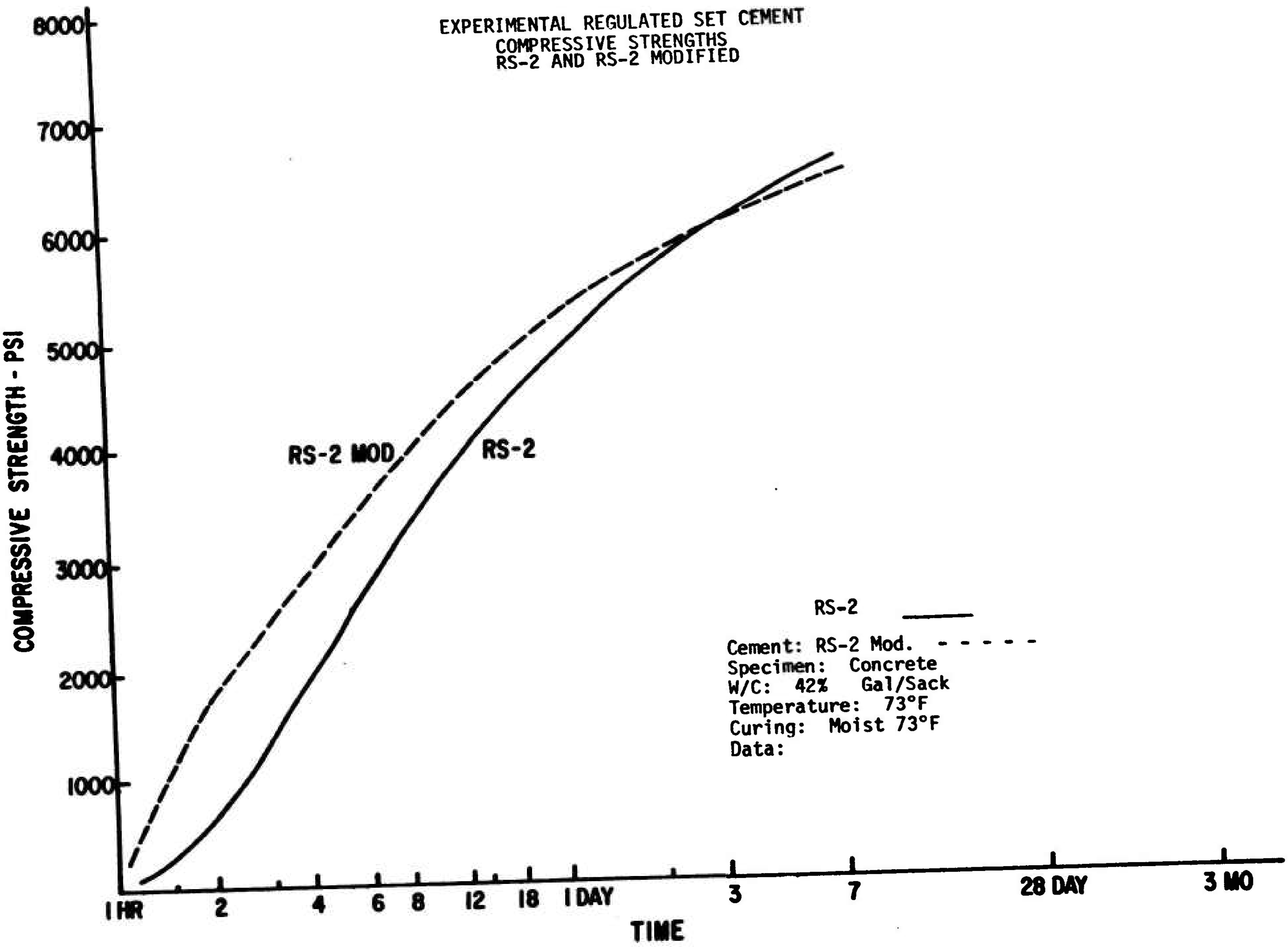



EXPERIMENTAL REGULATED SET CEMENT
RS-2 COMPRESSIVE STRENGTH
EFFECT OF RETARDER
.2% Retarder
Plain
Cement: RS-2
Specimen: Concrete
W/C: 42% Gal/Sack
Temperature: 73°F
Curing: Moist
Open Time - Plain 18 to 20 Minutes
Retarder 24 to 26 Minutes
Slump - Plain 2-1/4"
Retarder 3-1/4"
COMPRESSIVE STRENGTH - PSI
8000
7000
6000
5000
4000
3000
2000
1000
1 HR
2
4
6
8
12
18
1 DAY
3
7
28 DAY
3 MO
TIME

COMPARATIVE CONCRETE VOLUME CHANGE
TYPE I AND TYPE III vs. RS-2 AND RS-2 MODIFIED
6 SACKS/YD. .42 WATER/CEMENT RATIO



1/22/71
Data: Series 205, PCA, JLS


EXPERIMENTAL REGULATED SET CEMENT
COMPRESSIVE STRENGTHS
RS-2 AND RS-2 MODIFIED
COMPRESSIVE STRENGTH - PSI
8000
7000
6000
5000
4000
3000
2000
1000
RS-2 MOD
RS-2
RS-2
Cement: RS-2 Mod.
Specimen: Concrete
W/C: 42% Gal/Sack
Temperature: 73°F
Curing: Moist 73°F
Data:
1 HR
2
4
6
8
12
18
1 DAY
3
7
28 DAY
3 MO
TIME